U.S. Department of the Navy
Installation Restoration Program

REMEDIAL DESIGN WORK PLAN

SITE 01 - McALLISTER POINT LANDFILL CAP

NAVAL EDUCATION AND TRAINING CENTER
NEWPORT, RHODE ISLAND

TRC Project No. 14282-Q101-01
Contract No. N62472-86-C-1282

Prepared for:

Northern Division
Naval Facilities Engineering Command
Lester, Pennsylvania

August 1993

TRC Environmental Corporation

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1.0 INTRODUCTION AND BACKGROUND INFORMATION

This report presents the Work Plan for the design of a cap at the McAllister Point Landfill site at the Naval Education and Training Center (NETC) in Middletown, Rhode Island. TRC Environmental Corporation of Windsor, Connecticut is performing these services for the U.S. Department of the Navy, Installation Restoration Program through the Northern Division of the Naval Facilities Engineering Command under Contract N62472-86-C-1282. The decision to cap the site is described in a July 30, 1993 Proposed Plan.

The design of a cap for the landfill is considered a source control measure which provides containment and isolation of the landfill contents, the control of leachate generation as a result of infiltration, and the protection against surface erosion and landfill gas migration. The cap addresses the principal threats to human health and the environment posed by the site and is intended to be a permanent source control remedy for the site. Management of contaminant migration at the site will be evaluated by conducting a Phase II Remedial Investigation (RI) and by conducting a leachate generation and migration model study and by conducting an ecological risk assessment of the model study results. Major components of the landfill cap include:

- Capping of the landfill with a RCRA Subtitle C multi-layer cap.
- Shore protection to prevent cap damage from wave action and storm surge events cap.
- Landfill gas controls to manage landfill gas migration.
- Surface controls to minimize erosion and manage runoff.
- Use of fencing to control site access.

This document presents information pertaining to field exploration and design activities required to support the development and design of a cap. In addition the work plan outlines tasks to be conducted during and/or following the design activities. It is organized in the following manner.

Chapter	Contents
1.0	Introduction and Background Information
2.0	Sampling and Analysis Plan
3.0	Health and Safety Plan
4.0	Evaluation of Applicable or Relevant and Appropriate Requirements (ARARs)
5.0	Pre-Design Quality Assurance/Quality Control Plan
6.0	Initial Draft Construction QA/QC Project Plan

1.1 OBJECTIVES

The objective of this Work Plan is to define the work tasks necessary to design a cover system for the McAllister Point Landfill at NETC. The objective of the pre-design field sampling activities are to gather sufficient information on the nature of site geotechnical and landfill gas conditions to allow adequate consideration of these issues during the design of a cap for the site. The following project submittals are anticipated:

- Soil Boring Report for Landfill and Utilities
- Landfill Gas Summary Report
- Sediment Sampling Summary Report
- Leachate Generation, Fate and Transport Summary Report
- Leachate Ecological Assessment Report
- Draft and Final Landfill Cap Alternatives Summary Reports
- Plans, Specifications and Bid Documents
- Response to Review Comments

Each of the anticipated project submittals are described further in Section 2.0 of this report.

1.2 SITE DESCRIPTION

The McAllister Point Landfill is located within the Naval Education and Training Center (NETC) at the Newport Naval Base. The Newport Naval Base encompasses approximately six miles of the western shore of Aquidneck Island, Newport County, Rhode Island. Aquidneck Island is comprised of three towns; Newport, Middletown, and Portsmouth. The location of the Newport Naval Base is shown on Figure 1. The NETC serves as a training facility and provides logistic support for the Newport Naval Base. The NETC occupies approximately 1,063 acres of land. The location of the McAllister Point Landfill within the Newport Naval Base is shown on Figure 2.

The McAllister Point Landfill occupies approximately 11.5 acres between Defense Highway and Narragansett Bay. A site plan/topographic map is provided as Figure 3. The Penn Central Railroad tracks run in a north-south direction along the eastern side of the site, parallel to Defense Highway. Access to the site is from Defense Highway, across the railroad tracks, and through a gate in the south-central portion of the site.

Grass, weeds, and small trees cover most of the site. A small, lightly wooded area is present in the north-central portion of the site. A more mature wooded area is located near the northeastern edge of the site between the railroad tracks and Defense Highway. Several depressions are present in the central portion of the site where standing water collects during heavy precipitation events. A wetlands evaluation summary has been conducted at the site and is available within the Administrative Record. The Flood Insurance Rate Map (FEMA, 1984) which covers the site and surrounding area indicates the shoreline of the site lies within the 100-year coastal flood area. The western edge of the site along Naragansett Bay is a coastal bank that rises 10 to 15 feet above Mean Low Water. The areas of 100-year coastal flood in the vicinity of the site is 12 feet, and wave action may reach 17 feet. At high tide the beach is only about 10 feet in width while at low tide it may be as much as 50 feet wide. Metal debris and concrete rubble are present along the shoreline of the landfill. The presence of the concrete rubble and debris appears to have decreased the potential for erosion of the shoreline landfill slopes.

1.3 SITE HISTORY

The McAllister Point area of NETC was used as the site of a sanitary landfill from the mid 1950's until the mid-1970s. During this time the landfill was used for the disposal of wastes generated at the naval complex including wastes from all operational areas (machine shops, ship repair, Naval Underwater Systems Center (NUSC), etc.), Navy housing areas (domestic refuse), and from the 55 ships homeported at Newport prior to 1973 (approximately fourteen 40-cubic yard containers each day). The materials reportedly disposed of at the site included domestic refuse, spent acids, paints, solvents, waste oils (diesel, lubrication, and fuel), and PCB-contaminated transformer oil.

A review of historic aerial photos identifies a railroad spur entering the site near the current entrance and running north into the center of the site in 1938, and large open depressions and what appear to be material storage areas and tanks in the 1940s and 1950s. From 1965 through 1975, the shoreline of the central portion of the site changes shape, indicating filling of Narragansett Bay in this area.

During the period 1955 through 1964, wastes were trucked to the site, spread with a bulldozer, and covered. In 1965, an incinerator was built at the landfill. From 1965 through 1970-71, approximately 98 percent of all the wastes were burned before being disposed of in the landfill. The incinerator was closed around 1970 as a result of air pollution concerns. During the remaining years that the site was operational, wastes were again disposed of directly into the landfill.

Following the closure of the landfill at McAllister Point, a three-foot-thick covering of clay/silt was reportedly placed over the site. Current observations confirm the presence of a clay/silt material over portions of the landfill, although it is not continuous over the whole landfill area. Since the closure of the landfill, the site has remained inactive. In November 1989, the entire NETC was listed on the U.S. EPA's National Priorities List (NPL) of abandoned or uncontrolled hazardous waste sites.

1.4 PREVIOUS ENVIRONMENTAL INVESTIGATIONS

The nature and extent of contamination at the McAllister Point Landfill has been identified on the basis of the following site investigations:

- Initial Assessment and Confirmation Studies
- U.S. Army Corps of Engineers Study
- Phase I Remedial Investigation, and
- Planned Phase II Remedial Investigation.

Each of these investigations are summarized below.

1.4.1 Initial Assessment and Confirmation Studies

An Initial Assessment Study (IAS) was conducted at the site in 1983. The IAS (Envirodyne Engineers, 1983) identified sites at the NETC where contamination was suspected to exist and which may pose a threat to human health or the environment. Based upon historic use of the site as a landfill and the potential contaminant migration pathways at the site, the

McAllister Point Landfill was identified as an area of potential concern requiring further investigation (e.g., a Confirmation Study).

The Confirmation Study (Loureiro Engineering Associates, 1986), conducted on the site from 1984 to 1985, consisted of two phases, the Verification and Characterization Steps. During the Verification Step, seven sediment and mussel samples were collected from Narragansett Bay (including two background samples), two leachate samples were collected from the base of the landfill slope near Narragansett Bay, and one composite soil sample was collected from surface soils across the central portion of the site. During the Characterization Step of the Confirmation Study, an additional seven sediment samples were collected, two verifying the results at previous sampling locations and the remaining samples extending the area of sampling to the south and into the bay to the southwest of the site. Three mussels samples were also collected in the intertidal zone along the southwestern shore of the site. Three monitoring wells were installed on-site (MW-21, MW-22, and MW-23). These wells were each sampled on four occasions as part of Characterization Step investigations.

Analysis of the composite surface soil sample indicated that low levels of inorganic contaminants may be associated with the landfill cap material. Leachate spring samples from the western edge of the landfill exhibited cadmium, chromium, and cyanide, generally at concentrations less than 100 parts per billion (ppb). Ethylbenzene (30 ppb) and toluene (26 ppb) were also detected in one leachate sample. The sediment samples indicated the presence of inorganic contaminants in samples collected adjacent to the site, especially near the southern end of the landfill, with levels decreasing with increased distance from the site. Inorganics were also present in mussel samples. Polychlorinated biphenyls (PCBs), which were detected in mussel samples but not in sediment samples, did not appear to be site-related on the basis of the detection of levels in the control (background) mussel samples (0.36 and 0.37 μg/g) which were similar to near-site levels (non-detectable to 0.38 μg/g). Site ground water samples exhibited elevated levels of metals. The analytical results from the sampling are provided in the Confirmation Study Final Report (Loureiro Engineering Associates, 1986).

In summary, the Confirmation Study verified the presence of inorganics in site soil, heavy metals and volatile organic compounds (VOCs) in leachate, and elevated concentrations of inorganic contaminants in sediment, mussel, and groundwater samples collected at, or near, the site.

1.4.2 U.S. Army Corps of Engineers Study

In early March 1988, the Water Quality Laboratory Engineering Division of the U.S. Army Corps of Engineers (ACOE) collected a series of six sediment and mussel samples in Narragansett Bay near the McAllister Point Landfill. A seventh set of samples was collected at a location approximately 300 feet north of the site as a control sample. The sediment samples were analyzed for total petroleum hydrocarbons (TPH), PCBs, and six metals (cadmium, chromium, copper, nickel, lead, and zinc). The mussel samples were also analyzed for the same six metals. The sediment sample results indicated the presence of TPH at concentrations from 30 parts per million (ppm) to 1,100 ppm, PCBs from 0.01 ppm to 20.3 ppm, and the presence of elevated levels of metals. Concentrations in sediment samples collected adjacent to the landfill were generally at least one order of magnitude greater than concentrations in the control sample. Copper, chromium, zinc and PCBs were detected in some of the mussel samples at concentrations greater than were detected in the control sample.

In summary, the ACOE study confirmed the presence of elevated levels of metals in sediment and mussel samples near the site. In addition, elevated concentrations of TPH, PCBs were reported in sediment and mussel samples collected near the site.

1.4.3 Phase I Remedial Investigation

A Remedial Investigation (RI) was conducted at the site between 1989 to 1990 (Phase I RI). This investigation included site geophysical surveys and surface soil, subsurface soil, leachate and ground water sampling and analysis. It should be noted that surface soil sample locations were limited to portions of the site in which the clay/silt cap material was not present. The findings of the Phase I RI are summarized below.

Soil Assessment

A wide range of compounds including VOCs, base neutral/acid extractable organic compounds (BNAs) (including polynuclear aromatic hydrocarbons (PAHs)), pesticides, PCBs, and inorganics were detected in on-site soils.

The major areas of the site where soil contaminants were detected at elevated levels include the following:

- Northern area - Carcinogenic PAHs;
- North-central area - BNAs, carcinogenic PAHs, and inorganics;
- Central landfill area - VOCs, BNAs, PCBs and inorganics;
- South of access road - BNAs, carcinogenic PAHs, and inorganics; and
- Shoreline - BNAs, carcinogenic PAHs, and inorganics.

Soil - Volatile Organic Compounds (VOCs) - 1,1,1-Trichloroethane (1,1,1-TCA) was the only VOC detected in surface soil samples. This compound was detected at low levels (less than 12 parts per billion or [ppb]). VOCs detected in subsurface soils included 1,2-dichloroethene, 1,1,1-TCA, trichloroethene, benzene, tetrachloroethene, toluene, chlorobenzene, ethylbenzene, and xylene. In general, significant VOC contamination (i.e., greater than 1 ppm total VOCs) was detected in soils and fill in the central portion of the landfill area. However, VOC concentrations were not consistently elevated throughout the depth of the soil horizons sampled.

Soil - Base Neutral/Acid Extractables (BNAs) - The highest concentrations of total BNAs (greater than 100 ppm) were detected in four subsurface soil samples and two surface soil samples in the central and southern portions of the site at concentrations ranging from 194 ppm to 1,943 ppm. The highest total PAH concentrations (greater than 50 ppm) and carcinogenic PAH concentrations (22 ppm to 256 ppm) were detected in samples collected from the southern and northern ends of the landfill.

Soil - Pesticides/PCBs - The pesticides detected most frequently in site soils included 4,4-DDE, 4,4-DDD, and 4,4-DDT. The other pesticides detected, beta-BHC, aldrin, dieldrin, and alpha-chlordane, were each detected in only one sample. The highest pesticide concentrations were detected in surface soil (4,4-DDT at 1,800 ppb) at the southernmost end of the site, and subsurface soil (4,4-DDT at 2,300 ppb) in the central portion of the site.

PCBs are primarily present in the subsurface soils across the central part of the site, with nearly half (50%) of the sample locations containing detectable levels of PCBs. Some of the highest levels (>0.2 ppm) of PCBs detected at the site were detected in soil samples collected from the 22- to 24-foot interval. Four PCB Aroclors (Aroclor-1242, -1248, -1254, and -1260) were detected in at least one sample, with a maximum detected total PCB concentration of 1.1 ppm.

Soil - Inorganics - Inorganics levels in the site soil samples were compared to background inorganics levels, as defined by the analyses of two background surface soil samples collected east of Defense Highway. Based on this comparison, elevated concentrations of antimony, arsenic, barium, cadmium, calcium, chromium, cobalt, copper, lead, manganese, magnesium, nickel, silver, vanadium, and zinc are present on-site. Lead was particularly elevated (1,980 ppm) at one surface soil sample near the central portion of the landfill shoreline.

Ground Water Assessment

During the Phase I RI a total of nine ground water monitoring wells were installed across the site. Well locations are shown on Figure 3. Ground water samples were collected from all of the wells except MW-2, which was dry at the time of sampling. Three existing wells (MW-21, MW-22, and MW-23) and one leachate location (LS-1) were also sampled. A summary of site ground water quality is presented below. For the purpose of the Phase I RI, ground water contaminant levels were compared to existing federal and state action levels, including final, proposed, and tentative maximum contaminant levels (MCLs).

VOCs, BNAs, PCBs and inorganics were all detected in ground water samples. The major areas of the site where contaminants were detected at levels exceeding action levels include the following:

- Northern area - inorganics;
- North-central area - inorganics;
- Central landfill area - VOCs, and inorganics; and
- South of access road - VOCs, PCBs, and inorganics.

Ground water sample results indicated the presence of low level VOC contamination in the central and southern portions of the site, consisting mostly of aromatic VOCs (e.g., xylene and benzene). Low concentrations (1 to 160 ppb) of VOCs were detected in five of the ten on-site wells (MW-3S, MW-3D, MW-4, MW-5S, and MW-21). VOCs were also detected in soil boring samples collected at the depth of the water table from the north-central to southern portions of the site, indicating the potential for ground water contamination throughout this area. A thin oil layer was observed in one well (MW-5S) in the southern portion of the site five months after it was sampled.

BNAs were detected in three wells located in the central and southern portions of the site. The BNAs detected consisted primarily of PAHs and phenols. The highest level of total PAHs was 407 ppb at well MW-3S in the central portion of the site.

No pesticides were detected in ground water samples. A PCB concentration of 0.73 ppb was detected in the well in the southern portion of the site (MW-5S) in which a thin oil layer was subsequently observed.

The inorganic ground water sample results indicate the presence of numerous inorganic analytes in the ground water samples collected at the site. Inorganics were detected in each of the twelve wells sampled and in the leachate sample.

Additional information on the Phase I RI may be found within the RI Technical Report (TRC, 1991).

1.4.4 Planned Phase II Remedial Investigations

A Phase II RI will be conducted at the McAllister Point Landfill to further characterize the site and achieve the following objectives:

- Define background soil and ground water quality;
- Further define the nature and extent of site surface soil contamination;
- Further define the nature and extent of the fill material and any associated contamination;
- Further define the nature and extent of ground water contamination and the location of "hot spot" sources of ground water contamination;
- Determine the nature and extent of sediment and biota contamination in the adjacent bay.

The investigations will include the performance of geophysical surveys to further define the extent of the landfill area and to characterize bedrock topography beneath the site, a soil gas survey to further investigate subsurface areas of elevated VOC contamination in the central and southern portions of the site, and surface and subsurface soil, ground water and leachate sampling. An off-shore investigation involving the sampling of sediments and, if present, clams and mussels, and an ecological survey of marine fauna within the bay will also be conducted.

1.5 PRELIMINARY HUMAN HEALTH ASSESSMENT

A human health evaluation was conducted for the McAllister Point Landfill site on the basis of Phase I RI findings. The exposure scenarios considered in the human health evaluation of the site included both current use and potential future site use scenarios, as listed:

- **Trespassing Scenario (Scenario 1)** - Exposure of trespassing children from 9 to 18 years of age to site surface soils through dermal contact and incidental ingestion.
- **Recreational Use Scenario (Scenario 2)** - Exposure of children from 6 to 18 years of age (due to development of the site as a ballfield) to site surface soils through dermal contact and incidental ingestion.

- **Construction Scenario (Scenario 3)** - Exposure of adult construction workers for a period of one year to subsurface soils through inhalation, dermal contact and incidental ingestion.

- **Commercial/Industrial Use Scenario (Scenario 4)** - Exposure of adult employees through commercial/industrial use of the site to surface soils through incidental ingestion and dermal contact and to ground water through ingestion.

- **Residential Use Scenario (Scenario 5)** - Exposure of children from 0 to 6 years of age and adults (30-year period) to surface soil through dermal contact and incidental ingestion of soil/house dust and inhalation of particulates, and to ground water through dermal contact, ingestion and inhalation of volatiles.

Human health risks potentially associated with the site, which may include risks of cancer or non-cancerous (systemic) effects, were evaluated. Both average-case (based on the geometric mean of the on-site data) and maximum (based on the highest detected on-site concentration) risks were calculated. Cancer risk levels, the lifetime incremental probabilities of excess cancer due to exposure to the site contaminants, were estimated, taking into account exposure concentrations and the carcinogenic potencies of the chemicals. The cancer risk estimates are presented in scientific notation, where a lifetime risk of 1×10^{-4} represents a lifetime risk of one in ten thousand.

Health effects associated with exposures to non-carcinogenic chemicals were evaluated using U.S. EPA Risk Reference Doses (RfDs). The associated chemical-specific risk was quantified by the Hazard Index Ratio (HI), which is the ratio of the exposure dose to the RfD.

The calculated cancer risks and non-cancer His were evaluated using available regulatory guidance. The calculated risk is compared to the acceptable lifetime cancer risk range (1×10^{-4} to 1×10^{-6}) for evaluating the need for remediation, as stated in 40 CFR Part 300 (EPA, 1990b). EPA (1990b) considers a cancer risk of 1×10^{-6} as the point of departure for determining risk-based remediation goals. For non-carcinogenic risks, a target HI of unity is used (i.e., HI = 1). When the total HI for an exposed individual or group of individuals exceeds unity, there may be concern for potential non-cancer health effects. Thus, the cancer risk and HI ratios that constitute a potential concern are those which are greater than 1×10^{-4} and unity (1), respectively. Cancer risks which fall within the range of 1×10^{-4} to 1×10^{-6} (referred to as within the acceptable risk range) require further evaluation. The potential risks posed by the site in association with each scenario were evaluated, and the exposure pathway(s) driving the calculated risks are summarized below:

- **Trespassing Scenario (Scenario 1)** - Total cancer risks fall within the acceptable range; total His are acceptable (less than unity).

- **Recreational Use Scenario (Scenario 2)** - The maximum cancer risk value (1.3×10^{-4}), slightly exceeds the acceptable risk range. The mean risk value and total His are within acceptable values.

- **Construction Scenario (Scenario 3)** - The total cancer risk range and the mean HI are within acceptable values. The maximum HI (2.5) exceeded the acceptable value.

- **Commercial/Industrial Use Scenario (Scenario 4)** - The total cancer risks (1.8×10^{-3} and 3.9×10^{-3}) and the His (1.8 and 13) exceed acceptable values.

- **Residential Use Scenario (Scenario 5)** - The total cancer risks (ranging from 2.3×10^{-3} to 1.3×10^{-2}) and the His (ranging from 5 to 65) exceed acceptable values for both children and adult receptors.

For Scenarios 1, 2, and 3, the major contributing factor to the calculation of cancer risk is ingestion of carcinogenic PAHs in soil. The pathway of primary concern associated with Scenarios 4 and 5 with respect to cancer risk is ingestion of ground water containing inorganics (arsenic, beryllium) and carcinogenic PAHs. The primary contributor to the total His for Scenarios 1, 2, and 3 is ingestion of inorganics in soil. Ingestion of inorganics (antimony, arsenic, cadmium, chromium, copper, manganese, mercury and zinc) in ground water drives the total His for Scenarios 4 and 5.

While current risks posed by site surface soils to potential trespassers fall within the acceptable risk range of 1×10^{-4} to 1×10^{-6}, they exceed the point of departure risk level of 1×10^{-6}. Existing conditions at the site may pose a potential risk to the environment as well, due to the potential for contaminant migration via erosion, the continued generation of leachate as a result of the infiltration of precipitation, and ground water flow towards the bay. Additional assessment of site-related human health and environmental risks will be conducted as part of the Phase II RI. Placement of a cap over the landfill is intended to effectively eliminate exposure to contaminated surface soils. In addition, the cap will reduce infiltration of precipitation into waste material and thereby reduce leachate production.

2.0 SAMPLING AND ANALYSIS PLAN

2.1 INTRODUCTION

The objective of the Sampling and Analysis portion of this Work Plan is to present the scope of the field exploration activities to be conducted in support of the cap design at the McAllister Point Landfill in Middletown, Rhode Island. The findings of these exploration activities are intended to provide supportive documentation necessary to design a cap over the site in accordance with the July 30, 1993 Proposed Plan. In addition, this section provides a brief outline of the methods which will be used to evaluate data generated from pre-design activities.

The scope and rationale for the site survey, subsurface exploration, landfill gas, sediment, leachate generation fate and transport, leachate ecological risk assessment, and landfill cap design activities are presented in Sections 2.2 through 2.8. A summary of the planned pre-design sampling and analysis activities is presented as Table 1.

2.2 SITE SURVEY

Following completion of pre-design exploration activities the site will be surveyed by a State of Rhode Island registered surveyor. The physical site features along with the location elevation, and coordinates of pre-design boring and sediment sampling locations will be defined by the survey. The physical site features will be reproduced on a topographic site plan (at a scale of one inch equals 40 feet) with a one-foot contour interval from mean low water to the Defense Highway. Cross sections of the project area will be surveyed at 100-foot intervals. Wetlands flagging will be identified on the site topographic plan. In addition, three recoverable points will be established at the landfill with set horizontal and vertical coordinates for construction control purposes. All elevations will be referenced to mean sea level (MSL NGVD 1929) to the nearest 0.1 foot.

2.3 SUBSURFACE EXPLORATIONS

A series of subsurface explorations will be performed prior to initiation of design activities. These explorations are intended to provide data on the landfill fill and underlying native soil conditions and to assess the potential impact landfill gasses may have on the cap. Subsurface explorations planned at the landfill include the installation of four test borings, the construction of three vapor extraction wells and the installation of nine vapor probes. Each of these activities are described below.

2.3.1 Test Borings

A series of four test borings are planned at the site at the locations indicated on Figure 4. Boring locations have been selected to provide representative coverage of subsurface conditions at the landfill. The purpose of these borings is threefold: to provide additional data on the type and depth of landfill materials at the site; to allow collection of native soil samples under the landfill for geotechnical testing; and to allow access for the installation of three vapor extraction wells.

On-site drilling and vapor extraction well construction activities will be subcontracted to a qualified well drilling firm. Test borings will be advanced using 4¼-inch minimum inside diameter (I.D.) hollow-stem augers. The drilling activities will be conducted under the supervision of a TRC geologist/engineer. During drilling, split spoon samples will be collected at five foot depth intervals using a two O.D split-spoon sampler and standard penetration test (SPT) procedures as set forth in ASTM D1586. One 3.5-inch O.D. undisturbed thin-walled tube sample (Shelby Tube) will be collected from each boring from soil underlying the fill material, if compressible clay, silt, or organic sediments are encountered. Borings will be drilled to approximately 25 feet (estimated depth to competent bedrock) below ground surface. However, test borings will be terminated if auger refusal is encountered above 25 feet at a depth consistent with the top of competent bedrock.

The purpose of the collection of split-spoon samples will be twofold; first to define subsurface conditions in the area in which the vapor pilot test will be conducted, and secondly to collect samples of native soil underlying the fill for geotechnical testing. The physical characteristics of each soil/fill sample will be geologically logged and generally described by

TRC personnel in a field notebook. General observations may include fill type, staining, odors, oily soils, etc. Split spoon soil samples will be screened with an OVA and LEL immediately upon being opened. As indicated in Section 3.0, field screening for the presence of total VOCs and the presence of explosive gasses as well as oxygen content will be conducted during the drilling program.

Upon completion of the drilling program, one Shelby Tube soil sample per boring will be selected for geotechnical testing. This sample will consist of soil which, based on physical characteristics, appears to represent native soil underlying the fill and is amenable to collection using a Shelby Tube piston sampler (e.g., a sample with high silt, clay, or organic matter). The sample will be collected in such a manner as to minimize sample disturbance. Geotechnical analysis of these samples is described in Section 2.3.3 below. It is anticipated that these samples will be collected at or below the existing water table approximately 20 feet below ground surface.

Following completion of the boring, a vapor extraction well will be installed in three of the four test borings. The location of the vapor extraction wells is shown on Figure 4. Procedures for the construction and installation of these extraction wells is summarized in Appendix A. In general, each extraction well will be constructed of four-inch diameter PVC pipe consisting of a slotted screen section and solid riser pipe. Based on the current understanding of the fill thickness (3 to 24 feet) and average depth to ground water (about 20 feet), the screened interval will be established at approximately four to 17 feet below ground surface in each extraction well. This interval has been selected to provide a broad cross section of fill conditions, to be a minimum of two to three feet above the highest elevation of the water table (when a vacuum is applied to the extraction well, the static water level will rise), and to allow proper isolation of the screened interval from the ambient atmosphere.

Excess drill cuttings produced from the installation of the vapor extraction wells will be drummed and handled as described in the Investigation Derived Waste Plan, presented herein as Appendix B. Drill cuttings produced from the fourth test boring (where no well will be installed) will be backfilled into that borehole at the completion of the drilling activities. The top of this boring location will be backfilled level to the ground with a cement bentonite slurry, as described in Appendix A.

2.3.2 Vapor Probes

A series of nine vapor probes will be installed at the McAllister Point landfill. Three probes will be installed around each vapor extraction well in the configurations indicated on Figure 5. In general, the configurations shown are intended to provide information on horizontal changes in pressure and gas concentration around the central extraction well within each cluster. Specifically, vapor probe configuration A is intended to provide data on the distance-related heterogeneity of subsurface fill material, configuration B the direction-related heterogeneity and anisotropy, and configuration C a combination of both distance- and direction-related subsurface anisotropy and heterogeneity.

Individual probes will be constructed in the manner described in Appendix A. In general, each probe will consist of a one-inch diameter slotted PVC screen attached to a flush jointed riser pipe. Given the current understanding of site subsurface conditions described in Section 2.3.1 above, the screened interval of the vapor probes will be set from approximately ten to 15 feet below ground surface. Screening the vapor probes over this interval is intended to provide information on the average subsurface soil/fill air permeability and changes in landfill gas concentrations over time. Collection of landfill gas samples from the vapor probes is described in Section 2.4.1.

2.3.3 Geotechnical Analyses

As described above a series of four soil samples will be collected from native soils underlying the fill at the McAllister Point landfill. One sample per test boring will be collected for quantitative analysis of the geotechnical tests described below.

Incremental Consolidation Test (ASTM D-2435)

This is a one-dimensional test used to assess the total anticipated compression of a fine-grained soil under an applied load. This test provides data on the time rate of compression caused by the gradual decrease in sample volume caused by squeezing of pore water from the sample. Information generated by this test will be used to assess the potential additional settlement of the underlying soils which may be caused by the installation of a cap over the site.

Triaxial Compression Test with Pore Pressure Measurements (ASTM D-4785)

This test measures the shear strength of soil. In the triaxial compression test a cylindrical sample is confined by a membrane and lateral pressure is applied to the sample. Pore water drainage is controlled by tubing connected to the ends of the sample. This test allows for measurements of pore water pressure and soil shear strength testing under a variety of loading and drainage conditions. Information generated by this test will be used to assess potential slope stability concerns due to increased loads on the landfill from the installation of the cap.

Organic Content (ASTM D-2974)

This test measures the concentration of organic matter within a sample by combustion techniques. Data generated from this test may be used to assist in predicting contaminant migration rates and general soil properties.

Combined Sieve and Hydrometer Analysis (ASTM D-422)

This test determines the grain-size distribution of a soil sample from coarse to fine grained soils. Data generated from this test may be used to predict soil properties.

Atterburg Limits (ASTM D-4318)

This test is used to measure several physical properties of a soil such as liquid limit, plastic limit and shrinkage limit. Data from these tests may be used to predict soil shrinkage and swell characteristics as well as estimating the degree of sample preconsolidation. In addition, data generated from this test may be used to predict soil properties.

Specific Gravity (ASTM D-854)

This test measures the density of a soil sample. Data generated from this test may be used to predict soil properties.

The selection of samples to be submitted for laboratory analysis will be made by TRC geologists/engineers based on field observations of soil conditions.

2.4 LANDFILL GAS ASSESSMENT

Depending on the results of the landfill gas pilot testing described in Section 2.4.1 below, a landfill gas management system may be incorporated into design of the cap at the site. To assess the need for landfill gas control systems at the site, if any, pilot testing will be conducted on vapor extraction wells which will be installed within the landfill area. Data collected from the testing would be used to assess landfill gas composition and potential generation rates. This data would be evaluated to determine the need for, and possible options for landfill gas venting or extraction systems. The construction and installation procedures to be used for landfill gas extraction wells and vapor probes are described in Appendix A. Pilot scale testing procedures and data evaluation and analysis techniques are outlined below.

2.4.1 Pilot Testing

Each of the three landfill gas monitoring networks (e.g. A, B, and C) will be pilot tested to assess the potential impact subsurface landfill gasses may have on the air quality at the site and on the physical composition and integrity of the cap structure. Additionally, the results of the pilot testing will be used to design landfill gas controls, if needed.

Pilot testing will be initiated by the withdrawal of vapor from the landfill gas extraction well. At the start of the test pressure and landfill gas quality measurements will be collected at both the extraction well (through a sample port on the piping coming out of the well) and vapor probe using the sampling techniques described in Appendix A. The extraction pump is turned on and the test is started and measurements will be collected until such time as a steady state flow condition is observed (e.g., no significant change in pressure or gas quality for at least a ten minute period). The test will be terminated after steady state conditions are achieved. Pressure and gas concentration data will be measured during system recovery until pre-extraction conditions are achieved. Individual tests typically require several hours to set-up and complete and consist of the following steps:

- A vacuum pump with a minimum air flow capacity of 55 scfm at four inches of mercury is directly plumbed to the extraction well using PVC piping outfitted with a pressure gage and gas sample port.

- The teflon tubing at individual vapor probes are connected to a series of differential pressure gauges.

- The test is initiated by turning on the vacuum pump. Measurements of pressure and landfill gas quality (total VOCs, oxygen content and combustibility) are collected simultaneously from the sample port on the extraction well process piping and from the vapor probe.

- Measurements of time, pressure, temperature, flow rates and landfill gas quality are recorded until no significant changes are observed in any measurement for a period of at least ten minutes.

- The vacuum pump is turned off and measurements of pressure and landfill gas quality recovery are recorded until pre-pumping conditions are achieved. At this point the pilot test is terminated. If necessary, the test will be re-run to verify test data.

A series of eight landfill gas samples (including one ambient air blank sample) will be collected from the vapor extraction wells and vapor probes using the methods described in Appendix A. These samples will be analyzed for methane and volatile solvents using GC/MS techniques by modified EPA T01 and T02 methodologies. The selection of gas samples for quantitative laboratory analysis will be based on a number of factors including distribution of sample points over the landfill, relative indication of contamination (field screening results), soil boring observations, and time from initiation of the extraction test.

To ensure that vapors extracted from the landfill are not discharged directly to the atmosphere at a loading rate exceeding allowable limits, a 55-gallon carbon canister may be affixed to the effluent side of the vacuum pump. Effluent from the carbon canister will be periodically monitored to assess discharge air quality. Following completion of the testing, above ground equipment will be removed from the site. Spent carbon will be sampled and characterized prior to disposal/regeneration. Carbon canisters will remain on-site during sample analysis and selection of a regeneration/disposal facility.

2.4.2 Data Analysis and Evaluation

Data generated from the pilot-scale testing and field and laboratory analysis of landfill gas samples will be evaluated to determine the need for, and type of, gas control system to incorporate within the design of the cap at the landfill. Data evaluation will include modeling site data using HyperVentilate (V1.01 and V2.0) software. This software was developed by the U.S. EPA and Shell Oil Company to:

- Identify and characterize site-specific data,
- Decide if soil venting is appropriate,
- Evaluate pilot-scale testing (air permeability) data,
- Calculate the minimum number of extraction wells needed, and
- Illustrate deviation of site conditions from an ideal case.

Data produced from the test boring and pilot-scale testing programs may be used as input to the model to characterize site conditions. These data include: subsurface geologic and hydrogeologic conditions, contaminant identification and delineation factors and temperature conditions. While this model was developed to assess the general applicability and efficiency of soil vapor extraction at a site, it will be used at the McAllister Point landfill to assess the need for an active versus a passive gas control system, as necessary. Additional information on the HyperVentilate Model is provided in Appendix C.

2.5 SEDIMENT SAMPLING AND ANALYSIS

A series of six sediment samples will be collected from the shoreline of the McAllister Point Landfill at the locations indicated on Figure 4. Sediment sampling procedures are described in Appendix A.

2.5.1 Sediment Sampling

Considering the need to establish a stable, protected slope along the Bay portion of the landfill, it likely that sediment at the toe of the landfill slope may need to be excavated to place shoreline protection features (e.g., stone armored revetment). Therefore, sediment samples will be collected from the shoreline of the landfill to assess sediment quality consistent with RIDEM guidelines for sediment characterization. A copy of these guidelines are provided in Appendix D. In general, sediment samples will be collected as composite samples over a depth interval consistent with the proposed sediment excavation depth of two to four feet below existing grade.

Depending on the results of the chemical analysis of the samples described in Section 2.5.2 below, the excavated sediment will likely be placed on the top of the landfill, and then subsequently covered with the cap.

2.5.2 Sediment Analyses

As indicated on Table 1 all six of the sediment samples will be quantitatively analyzed for the following general quality parameters:

- Grain Size Distribution
- Moisture Content
- Total Solids
- Total Organic Carbon
- Specific Gravity
- Total Sulfides
- Ammonia

In addition, a subset of four samples will be quantitatively analyzed for the following toxic parameters:

- Full Toxicity Characteristic Leaching Procedure (TCLP) parameters
- Full Target Compound List (TCL) parameters
- Full Target Analyte List (TAL) parameters
- Total Petroleum Hydrocarbons
- Oil and Grease

Analytical methods are described in Section 5.0. In general, of the six general quality sediment samples, four will be collected as vertical composite samples over the anticipated depth of sediment excavation (two to four feet below existing ground surface). The remaining two samples will be collected from the upper six inches of sediment. Each vertical composite sample will be collected from a single location. Sediment samples which will be analyzed for toxic parameters will be selected from the six samples based on field consideration of sample distribution, evidence of discoloration, odor, or unusual characteristics.

2.6 LEACHATE GENERATION FATE AND TRANSPORT ASSESSMENT

The objective of the capping action at the McAllister Point Landfill is to provide containment and isolation of the landfill contents through the control of leachate generation as a result of infiltration. Through this action, exposures to the landfill area will be limited and continued migration of contamination leached from the waste materials located within the unsaturated zone into the ground water will be minimized. To assess the reduction in leachate generation which will be achieved by the placement of an impermeable cap over the landfill, a leachate generation fate and transport assessment will be conducted. This assessment consists of two basic components. An assessment of the volume of leachate generated following cap placement and an assessment of the fate and transport of leachate and residual leachate which will be produced following the capping action. Each of these components are described below.

The leachate generation fate and transport assessment will be conducted following the completion of the collection of additional field and laboratory data for the planned Phase II RI program. The Phase II RI program will supply the necessary additional soil, ground water, and hydrogeological parameters required as input for the assessment. This includes the collection of the long-term tidal influence measurements for selected monitoring wells.

2.6.1 Leachate Generation Assessment

To evaluate the quantity of infiltration (therefore leachate generation) which may occur following construction of the cap system, the cap system will be simulated using a nationally recognized model, the Hydrologic Evaluation of Landfill Performance (HELP) computer program. The HELP model was developed by the U.S. Army Corps of Engineers Waterways Experiment Station for the U.S. EPA. This program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts climatologic, soil and design data and utilizes a solution technique that accounts for the effects of surface storage, runoff, infiltration, percolation, evapotranspiration, soil moisture storage, subsurface inflow, and lateral drainage. Landfill systems, including various combinations of vegetation, cover soils, waste cells, special drainage layers and relatively impermeable barrier soils, as well as synthetic membrane covers and liners, may be modelled. The program was developed to facilitate rapid estimation of the amounts of runoff, drainage and leachate that may be expected to result from landfill operation under a wide variety of landfill designs. The model is applicable to open, partially closed and fully closed sites.

Numerical modeling is the process in which a physical system is first described by analytical mathematical equation(s) and then simulated by numerical approximations of mathematical solutions using a digital computer program to predict its physical processes. This modeling process is necessarily based on many simplifying assumptions. The major assumptions for the HELP program are summarized below.

The HELP model computes the rainfall-runoff on a long-term based statistical average, and therefore cannot provide accurate estimates of runoff volume for individual storm events. It assumes Darcy flow through the soil and does not consider any channeling flow due to soil characteristics such as cracks or root holes. The lateral drainage rate and average saturated depth have been assumed to support the unsaturated drainage as a steady state drainage.

The HELP program requires three general types of input data: climatological data, soil data and design data. The default climatological data of Providence, Rhode Island will be used as input to the HELP model. This data includes five years of historical precipitation data (1974 through 1978). Maximum leaf area index and evaporative zone depth corresponding to vegetative cover of fair grass may also be assumed.

Soil data required as input to the model includes the number of layers in the cap, layer types (i.e., vertical percolation, lateral drainage or barrier soil liner), layer thickness, soil texture, soil compaction, initial soil water content, leakage fractions for synthetic membrane liners, vegetative cover type, and runoff curve number.

Design data are also required in the HELP program and include such information as the total landfill surface area, slope of a lateral drainage layer, and maximum lateral drainage distance along a slope. Each of these data will be determined during the cap design. A preliminary assessment of the quantity of leachate which may be generated by the placement of a RCRA Subtitle C landfill over the site indicated that approximately 600 to 700 gallons of leachate may be generated on an annual basis. Further information on this preliminary estimate may be found within the Final Focussed Feasibility Study for the site.

2.6.2 Leachate Fate and Transport Assessment

Based on the results of the leachate generation assessment described above, a leachate fate and transport assessment will be conducted. This assessment will consist of three major components:

- A qualitative description of the leachate generation and potential migration pathways will be presented. This description will provide the foundation and conceptual framework for the quantitative analysis.
- A quantitative assessment will be performed. This assessment will use existing site data as input to a model (MODFLOW) which will provide information on the anticipated rate of leachate migration that might be expected at the landfill.
- Potential future migration will be evaluated using information supplied by the leachate generation assessment and migration assessment.

It is assumed that the leachate generation will migrate downward into ground water and migrate in the aqueous, or dissolved ground water phase. Therefore, leachate fate and transport properties will be modelled using a three-dimensional ground water flow model. The model chosen for this assessment is the USGS MODFLOW model which has been selected based on the programs ability to provide a realistic numerical characterization of the existing aquifer system beneath the landfill. MODFLOW is a public domain model that approximates ground water flow using a finite difference technique. Information required as model input include such aquifer properties as porosity, hydraulic conductivity, adsorption, dispersivity, and initial pressure and concentration conditions. These data will be estimated from existing site-specific data (Phase I RI) and information available within the literature. Model output will include information on the three-dimensional rate of leachate migration at the landfill and would form the basis for a future impact assessment. This assessment would estimate the impact leachate migration may have on Narragansett Bay based on predicted leachate loading and migration rates. In addition, the future impact assessment would evaluate natural ground water flow and transport (e.g., flushing) of the landfill following cap placement.

2.7 LEACHATE ECOLOGICAL RISK ASSESSMENT

To assess the need for mitigation of the landfill leachate in the post-capping scenario, an ecological risk assessment and characterization will be performed to determine potential adverse effects of leachate on environmental receptors in Narragansett Bay. The ecological assessment and risk characterization are described below.

To undertake the ecological risk assessment modeled ground water concentrations will be used to simulate the loading of landfill contaminants into the Bay. The accumulation of these contaminants in sediment and biota will be calculated based upon partition coefficients and bioconcentration factors. Resulting environmental concentrations (water column, sediment, biotic tissues) will be compared against available environmental quality criteria. Additionally, contaminant exposures will be compared against acceptable exposures to marine biota (plants, macroinvertebrates, shellfish) to derive Toxicity Quotients. The Toxicity Quotient will provide a quantitative measure of the acceptability of the modeled exposures. Exposure concentrations likely to be devoid of ecological harm will be determined from the marine toxicology literature for the chemicals of interest, with computerized searches of fish and wildlife databases providing the vehicle to locate appropriate toxicity data.

The habitats and species potentially impacted will be assessed based upon evaluation of previous benthic studies of Narragansett Bay, and based upon current site-specific data gathered in the Bay just off of McAllister Point. These data will describe the habitats and species involved so that rare, threatened, or endangered species and habitats can be identified. An endangered species search will also be conducted using local databases which report the siting of endangered species in specific locations. The habitat and species data will provide an index of species diversity and enumeration, presence of special concern species and background concentrations of chemicals in species tissues and sediment due to previous releases. This data will provide an indication of whether adverse biological impacts are evident in the region of McAllister Point.

The ecological risk assessment will be divided into the following tasks:

- Hazard Assessment - identify contaminants of concern and receptors of concern; characterization of the ecological resource and associated habitats.

- Toxicity Assessment - evaluate the dose response relationships describing the marine impacts of the contaminants of concern; identification of environmental concentrations criteria relevant to the marine media of concern.

- Exposure Assessment - identify biotic exposure pathways stemming from contamination of the water column, sediment, and food resources; model exposure point concentrations in these media; evaluate the likelihood for exposure to occur.

- Risk Characterization - calculate Toxicity Quotients for quantifiable risks; compare modeled concentrations to available criteria; evaluate sensitivity and uniqueness of the ecosystem and specific receptors in terms of the contaminant exposures; discuss potential impacts in relation to background concentrations and risks.

2.8 DESIGN OF THE LANDFILL CAP

A conceptual level description of the cap at the McAllister Point Landfill is provided below.

A multi-layer cap would be placed over the landfill area to limit the amount of infiltration and thereby minimize leachate production. The cap would cover approximately 10.5 acres, encompassing the landfill area at McAllister Point, including identified areas of ash, construction debris and domestic waste disposal. The general area where the cap would be placed is indicated on Figure 6. The cap would be designed to meet or exceed Resource Conservation and Recovery Act (RCRA) guidance as described in the USEPA documents, Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments (USEPA, 1989) and Design and Construction of RCRA/CERCLA Final Covers (USEPA, 1991), and in accordance with accepted engineering design practices. Site-specific factors will be considered in determining an effective cap design. A typical cover system is composed of a vegetative and protective layer, a drainage layer, an upper barrier layer consisting of a synthetic membrane, and a lower barrier layer consisting of a low permeability soil barrier. An optional gas vent layer may be placed below the lower barrier layer, if determined to be appropriate during the landfill gas management system evaluation. A conceptual cap cross-section is provided in Figure 7.

A landfill gas management system would be incorporated into the cap design if necessary. As part of the design phase, a landfill gas study would be conducted as described in Section 2.4 above.

Surface controls, including grading, re-vegetation, storm water runoff and slope protection would be implemented in conjunction with the multi-layer cap.

Prior to construction of the cap, the site would be regraded to eliminate depressions and steep sidewalls to the extent practicable so that precipitation will run off instead of ponding on the surface or infiltrating into the landfill and to provide stable slopes. The regraded surface will also enhance the placement of the cap materials over the landfill area, especially along the steep sidewall areas adjacent to Narragansett Bay. Near-shore sediments may need to be excavated from below the mean high water line for placement of shoreline protection features.

Regulatory permission to excavate and consolidate this sediment within the proposed cap area prior to initiation of cap construction activities will be sought.

Following cap construction, the entire cap would be seeded and/or planted to minimize erosion of the cap's surface. A re-vegetation analysis will be conducted to allow development of a re-vegetation plan which will enhance future habitation of the site by indigenous species. This analysis will be conducted by a qualified ecological consulting firm.

The cap and drainage system would be connected to a system of drainage swales around the landfill to control run-on and run-off. Along the western side of the landfill, bordering Narragansett Bay, slope protection revetment would be utilized to protect the landfill materials and the landfill cap from potential damage due to wave erosion, storm surges, etc. During the design process, a storm surge and wave analysis will be conducted to evaluate wave energy forces along the shoreline and maximum wave runnup in order to design protection of the slope. A stability analysis of the existing and/or any proposed modifications to the existing side slope will also be conducted during the design process. The final design of the slope protection system would be in accordance with the Army Corps of Engineers' Shore Protection Manual and available FEMA coastal flood elevation information. Any reduction in the grade of the seaward-facing landfill slope would be designed so as to consolidate any material removed from the slope in the area to be capped and to minimize any movement of landfill material into the adjacent bay. In accordance with Section 404 of the Clean Water Act, the slope protection features along Narragansett Bay should not extend beyond the toeprint of the existing landfill. If during the design process it is determined that the cap cannot be constructed in accordance with this requirement, mitigation of impacted wetlands may be required. If mitigation is required, a mitigation plan will be developed and distributed for public comment prior to implementation. A conceptual slope protection section is provided in Figure 7.

Adjacent to the remainder of the cap's perimeter, drainage swales would be used as necessary to control run-on and run-off from the cap.

2.8.1 Long Term Monitoring Review

It is anticipated that a thirty-year period of post-closure care will be required following completion of the landfill cap. Post-closure care would consist of the following components, in accordance with RCRA requirements (40 CFR Part 264, Subparts G and N):

- Maintaining the integrity and effectiveness of the final cover, including making repairs to the cap as necessary to correct the effects of settling, subsidence, erosion, or other events;
- Maintaining and monitoring the ground water monitoring system and complying with other applicable requirements of 40 CFR 264 Subpart F;
- Maintaining and operating the gas control and monitoring system;
- Preventing run-on and run-off from eroding or otherwise damaging the final cover; and
- Protecting and maintaining surveyed benchmarks used in complying with 40 CFR 264.309.

Long-term ground water monitoring and storm water discharge monitoring would be conducted following capping of the landfill. The design of the monitoring systems would be defined following completion of additional ground water studies and site drainage design. The environmental monitoring program would be submitted for regulatory review and would identify the sampling locations and sampling frequencies. At a minimum the environmental monitoring program would be conducted for a period of thirty years.

Five-year reviews would also be required as part of the environmental monitoring program. In addition to making recommendations regarding future remedial actions, the five-year reviews would assess the performance of the containment system to ensure continued protection of human health and the environment.

3.0 HEALTH AND SAFETY PLAN

This Health and Safety Plan (HASP) has been developed to guide TRC's health and safety procedures which will be used during field investigations for the design of a landfill cap at the McAllister Point Landfill. This HASP is intended to meet requirements for protection of worker health and safety required by the Occupational Safety and Health Administration (OSHA) under 29 CFR 1910.

3.1 HEALTH AND SAFETY OBJECTIVES

The objectives of this HASP are to:

- Inform site personnel of the currently known and suspected hazards associated with work at contaminated areas at the McAllister Point Landfill;
- Provide a safe work environment;
- Minimize the risk of injuries and illness for site workers and the public; and
- Comply with safety and health laws and regulations.

All site personnel, including subcontractors, are required to become familiar with and follow provisions of this plan. Although all employees are required to follow the guidelines set forth herein, the safety of site personnel is ultimately the responsibility of the individual and their respective employers. Copies of this HASP will be available to on-site personnel for orientation to anticipated on-site hazards (based on currently available data), as well as the health and safety procedures to be followed during implementation of this program. TRC and the Navy cannot be responsible for enforcing provisions of this plan for the health and safety of site personnel other than their own employees.

3.2 HEALTH AND SAFETY ORGANIZATIONAL STRUCTURE

This section focuses on TRC's organizational structure in specific relation to health and safety. The main points-of-contact between the Navy and TRC are TRC's Program Manager and Project Manager. TRC's Health and Safety Director provides consultation to the Program and Project Manager on health and safety issues as well as industrial hygiene concerns. Field operations are directed by the project manager in coordination with the Navy and the Program Manager. These operations are headed by a Field Operations Manager, who has control of day-to-day field activities during on-site work. Day-to-day control of worker health and safety is conducted by the TRC On-Scene Coordinator (OSC) who reports directly to the Field Operations Manager, or, in his or her absence, the TRC Project Manager. While individual subcontractors are required, or at a minimum encouraged, to develop their own health and safety plans they must follow the requirements of this HASP.

Responsibilities of key health and safety personnel are described below. These personnel will be involved with the development and/or modification of this HASP for task-specific work activities at the site. Modifications of this HASP will be reviewed and approved by key supervisory staff.

Program Manager

- Holds ultimate responsibility for satisfactory completion of the project.
- Reports status of field activities to the Northern Division Project Manager.

Health and Safety Director

- Reviews and provides input to subcontractor-generated health and safety plans.
- Provides on-going industrial hygiene support to the Project Manager.
- Reviews and approves significant changes and/or deviations to the HASP.
- Provides consultation to the Project Manager on technical aspects of the HASP and its implementation.

Project Manager

- Provides overall project management and control.
- Maintains day-to-day liaison with the Northern Division technical staff and subcontractors.
- Prepares, reviews, and transmits project documents to the Navy.
- Conducts the initial health and safety site orientations.
- Notifies the Navy technical staff of any site emergencies.
- Conducts field health and safety audits, as necessary.

Field Operations Manager

- Coordinates and supervises fieldwork.
- Reports daily progress of fieldwork to the Project Manager.
- Notifies Project Manager of deviations from the Health and Safety Plan.
- Assures that fieldwork proceeds according to Health and Safety Plan requirements.
- Designates On-Site Coordinator (OSC)

On-Site Health and Safety Coordinator (OSC)

- Monitors field investigations to ensure compliance with the approved HASP.
- Recommends modification of the HASP to the Project Manager as soon as practical after it is apparent that the Plan should be modified.
- Primary responsibility for notification of and transport of injured field personnel to a hospital in the event of an accident.
- Keeps non-essential personnel outside study zone boundaries. Logs in the field notebook personnel who enter into the study zone.
- Uses appropriate portable field instruments to monitor site conditions during investigatory activities.
- Maintains a log of field activities, monitoring data, and site meetings.
- Monitors decontamination procedures for personnel and equipment.
- Monitors the handling and storage of investigation-derived waste materials.
- Appoints alternate on-site coordinator on an as needed basis.

On-Site Health and Safety Coordinator - Alternate(s)

- Assumes all functions and responsibilities of the OSC in his/her absence.

Subcontractors

- Immediately notify the Field Operations Manager or On-Site Coordinator of hazardous or potentially hazardous conditions or environments that are not addressed or not adequately addressed in the HASP.
- Conduct work in a safe manner.

3.3 MEDICAL SURVEILLANCE

TRC maintains a continuous in-house medical surveillance program designed specifically for field personnel engaged in hazardous waste site activities. This program is maintained in compliance with 29 CFR 1910.120(f) and is intended to assess and monitor personnel exposure to hazardous and/or toxic agents. As indicated in EPA's Standard Operating Safety Guides (pg. 79), the goal of a medical surveillance program, and of appropriate screening and monitoring in the workplace, is the protection of an employee's health. Two factors are critical for achieving this goal:

- Detecting pre-existing disease or medical conditions that may place an employee performing certain tasks at an increased risk; and
- Minimizing individual exposures at the workplace, so that the disease process is never initiated.

A consulting, board-certified, occupational physician and TRC's Health and safety Director will conduct and oversee TRC's medical monitoring program. Clinical laboratory testing protocols will be determined by the examining physician. TRC's company physician (Dr. Michael Erdil) is a specialist in occupational health. Dr. Erdil's address is:

Mr. Michael Erdil, M.D.
Immediate Medical Care Center
423 Franklin Avenue
Hartford, CT 06114
Phone (203) 296-8330

Each TRC employee must have medical clearance from the Health and Safety Director prior to commencement of site work. Medical evaluations are conducted on a yearly basis according to the outlines described in this section. The purposes of the medical monitoring program are as follows:

- To assess the health status of an employee prior to work;
- To evaluate and provide medical care for personnel in the event of a work-related accident or illness;
- To identify any adverse health effects resulting from hazardous work and to determine employee fitness for future work assignments.

Additionally, it has been TRC's experience that a medical monitoring program generates a sense of health and safety conscious among project personnel. Pre-placement, exposure and follow-up medical evaluations are described below.

Pre-Placement Medical Evaluation

Employees whose work assignments require their presence at a hazardous work site are required to have a baseline medical evaluation prior to commencement of hazardous work activity. The baseline medical evaluation consists of the following.

- Medical and Occupational History
- Physical Exam
- Pulmonary Function
- Urinalysis
- CBC (with differential and RBC) Chem 24 (SMAC)
- RBC Cholinesterase
- Urine Heavy Metal Panel
- Blood Lead
- Blood PCBs
- EKG (over 40 years of age)
- Audiometry

In addition to the initial baseline medical evaluation, an annual medical evaluation is conducted for TRC employees. The annual medical evaluation consists of the following:

- Physical Exam and History
- Pulmonary Function
- Urinalysis
- CBC (with differential and RBC) Chem 24 (SMAC)
- RBC Cholinesterase
- Blood Lead
- EKG (over 40 years of age)
- Audiometry

Additional tests which may be performed as part of the annual examination include the following:

- Cholinesterase (plasma)
- Urine Heavy Metal
- Chest X-Ray (2-view)

Based upon this examination and a review of the employee's job description, the physician identifies any medical restrictions which would affect an employee's ability to safely perform his/her job. If no restrictions are imposed, the physician certifies the employee as capable of conducting work at hazardous waste sites. The examining physician communicates any medical restrictions directly to the employee and TRC Health and Safety Director, if appropriate.

Exposure Medical Evaluation

If an employee suspects exposure to a toxic chemical or other hazard while performing project tasks, additional tests may be conducted following the exposure period. Individuals are encouraged to discuss potential exposure events and changes in their health status with their physician and/or the TRC Health and Safety Director.

Follow-up Medical Evaluation

Each person who participates in hazardous work activity has an annual medical examination. The evaluation consists of the following:

- Basic medical evaluation (as described above); and
- Additional medical testing as dictated by hazardous work history and other health status changes during the previous year.

The health care facility is required to retain TRC medical records for a minimum of five years.

3.4 HEALTH AND SAFETY TRAINING

The TRC field personnel who may be assigned work activities at the McAllister Point Landfill have completed OSHA required safety training programs, and will undergo site specific safety instruction prior to the start of field work. Both OSHA and on-site training programs are discussed below.

3.4.1 OSHA Training

TRC personnel receive training which, at a minimum, satisfies the OSHA regulations for hazardous waste and emergency response (29 CFR 1910.120). TRC personnel assigned to hazardous field work undergo both classroom and practical training relative to general health and safety and respirator use. Both programs are described within this section.

TRC personnel who participate in on-site work activities which may result in exposure to a toxic or hazardous material are required to complete a 40-hour OSHA safety training program, as well as yearly refresher programs to:

- Ensure maximum regard for the health and safety of fellow employees, the public, and the environment;
- Comply with laws, rules, and regulations required to safeguard the health and safety of employees, the public, and the environment;
- Increase the ability of employees to react responsibly and safely under normal conditions and during emergency situations; and

- Educate personnel relative to potential hazards, adverse chemical effects, and the importance of safety and industrial hygiene practices.

TRC hazardous waste site investigation personnel who may work at the McAllister Point Landfill have attended a course (or its equivalent) which includes discussion of many topics in dealing with hazardous substances. The course was comprised of classroom instruction, demonstrations, respirator fit testing, protective clothing outfitting, and hands-on field safety training.

A typical training course includes, at a minimum, the following topics:

1. Identification of hazardous substances
2. Properties of hazardous substances
3. Routes of exposure
4. Toxicity
5. Practical considerations
6. Physical properties of chemicals
7. References for TLV, LEL, toxicity data, cross references
8. Remote sensing, map reading
9. Technical assistance organization
10. Air monitoring and survey instruments
11. Site entry and egress procedures
12. Heat stress monitoring
13. Levels of personnel protection
14. Site control - work zones
15. Site control - decontamination
16. Equipment decontamination
17. Site/Area safety planning

The emphasis of the training is that a certain level of protection must be maintained throughout the field work. Even though exposure may be minimal, it is emphasized that field team members can develop synergistic symptoms and health effects by exposures at various sites to different chemicals. The levels of protection used on any site will be dictated by the level of risk and the known or anticipated exposure.

3.4.2 Respirator Training

All personnel who enter an Exclusion Zone must have completed a respiratory protection program which, at a minimum, satisfies OSHA regulations (29 CFR 1910.134). This program includes:

- Instruction in the proper use and limitations of respirators;
- Proper fitting of personnel for a respirator, using a qualitative or quantitative fit test method; and
- Teaching personnel how to conduct a positive and/or negative fit test.

Each employee will be fit tested with their individual respirator. During in-house safety training, employees are fit tested using isoamyl acetate (banana oil) and irritant smoke in accordance with 29 CFR 1910.134(e)5(i) and EPA protocol as described in "Hazardous Material Incident Response Operations Manual, Appendix III, Respirator Fit Testing". On-site fit testing will consist of a qualitative fit test such as the negative pressure test or positive pressure test. In conducting the negative pressure test, the employee will be told to close off the inlet of the canister, cartridge(s), or filter(s) by covering them with their palms or by squeezing the breathing tube so it doesn't pass air. They will then be told to inhale gently so the face-piece collapses slightly and then to hold their breath for ten seconds. If the face-piece remains slightly collapsed and no inward leakage of air is detected, the fit is considered to be satisfactory.

In conducting the positive pressure test, the employees will be told to close off the exhalation value and then to exhale gently into the face-piece. If a slight positive pressure can be built up inside the face-piece without any outward leakage, the fit is considered to be satisfactory. Because this test may require removal and replacement of the exhalation valve cover which can disturb the respirator fit, it is a less preferred method than the negative pressure test.

Field staff assigned to project work at the site shall be capable of using and inspecting a cartridge respirator. Each field staff shall have their own personal respirator. The maintenance of that respirator shall be the responsibility of the individual. OSHA requires that respirators be inspected both before and after use and that respirators not used routinely shall be inspected after use and at least monthly. At the time the respirator is issued and used, the individual receiving it shall test the fit (qualitatively), and inspect the gaskets, exhalation valve, face shield, head straps, and cartridges.

Individuals are responsible for cleaning/disinfecting their respirators. Acceptable procedures include washing using respirator-approved detergent/disinfectant in warm water and rinsing or air drying in a clean place.

3.4.3 First Aid Training

Most members of TRC's field investigation staff have received red Cross first aid and CPR training. The TRC project manager and OSC will consider the need for personnel trained in first aid and CPR when assembling and scheduling field investigation crews.

3.4.4 Site-Specific Training

Before field work starts at the site, the TRC Project Manager or his/her designee will conduct an on-site training course for TRC and subcontractor personnel, and other people involved with site investigations. No person will be allowed to work on-site unless they have attended this or some other appropriate form of safety training. This training program will include a review of this HASP, copies of which will be made available to all attendees and which will be available at all times at a central command location. The major components of the training will include:

1. Review of suspected chemical hazards, forms (vapor, gas etc.) and warning properties.

2. Operational Procedures
    - Site command control
    - Perimeter control
    - Zones of hazard
    - Levels of protection
    - Detection equipment
    - Communications (radio and hand signals)
    - Decontamination procedures

3. Emergency procedures
   - First aid
   - Emergency communications
   - Local response groups and their phone numbers
   - Evacuation procedures

Site rules and regulations that will be emphasized during the on-site training are:

1. No smoking, drinking, eating within restricted zones. A respirator is required to be worn at all times within this zone unless organic vapor/gas levels are determined to be within recommended safe limits based on OVA readings and do not pose a health hazard to workers.

2. All resting, refreshment and sanitary facility use will be in clean areas.

3. Those in contact with contaminated soils, sludges or other suspect contaminated materials must go through full decontamination upon egress from restricted areas.

4. The On-Scene Coordinator or his designee has full authority in terms of startup and shutdown of operations from a safety standpoint. The OSC will determine if upgrades of personal protective equipment is warranted and/or if weather conditions are too extreme for work.

3.4.5 TRC's Drug- and Alcohol-Free Workplace Policy

TRC has a continuing objective to provide the highest quality service to its clients and to safeguard their employees. Therefore, TRC has established a policy to maintain a drug- and alcohol-free workplace for the benefit of TRC employees, clients, business associates, and the public. This policy is intended to be consistent with the Drug-Free Workplace Act of 1988 and incorporates drug and alcohol testing for specific categories of employees. Further information on TRC's Drug- and Alcohol-Free Policy is available upon request.

3.5 OPERATIONAL PROCEDURES

The purpose of the operational control measures presented in this section are to maintain order at the site and to minimize chemical and physical hazards to on-site personnel, visitors, and the public. As required by OSHA under 29 CFR 1910.120(d), the following site control program has been developed prior to implementation of response actions.

3.5.1 Site Command and Control

A command post vehicle will be used to store safety and decontamination equipment used during exploration activities at the landfill. This vehicle will serve as the command center. Personnel traveling with this vehicle will be in radio contact with the TRC project manager.

An area near the command vehicle will serve as the command post and will be designated a "clean area" where only Navy personnel, the TRC project manager, the Field Operations Manager, and the On-Scene Coordinator will be allowed. All other people must have clearance from the OSC or his designee before being allowed access to this area. Emergency response telephone numbers, directions to the nearest hospital, and this Safety Plan will be available at the command vehicle.

Security

Security within the Newport Naval Base is provided by a series of restricted access gates which are manned by security personnel. However, access to the McAllister Point Landfill area along Defense Highway is restricted by a chain-link fence and locked gate.

Site Documentation

Documentation and implementation of this Health and Safety Plan will be maintained within TRC's project files. The following information shall, at a minimum, be recorded:

- Signed copies of the HASP Approval Form provided at the front of this document.
- Signed copies of the Personal Safety Acknowledgement Form for personnel who engage in field work at the landfill.

Any completed accident Report Forms.

Copies of Health and Safety Training certificates and physician's acknowledgement of the fitness of employees to engage in normal field work.

Additionally, copies of health and safety reference material, and records of environmental monitoring equipment calibration and usage may be maintained in the project files. Further site information will be recorded in daily logs of field activities maintained by TRC site personnel.

3.5.2 Site Communication

Internal and external communications systems will be established during field activities. Internal communication refers to communication between workers at a job site. External communication refers to communication between on and off-site personnel. TRC's internal communication system will consist of the use of portable walkie-talkies and/or telephones or the use of emergency hand signals, when respiratory protection is used and personnel are within visual contact. A general summary of an internal site communication system is outlined below.

Field Teams:

Portable FM walkie-talkies - one mile range
Telephone

Field Personnel:

Hand signals (see below)

EMERGENCY HAND SIGNALS

1. Hand gripping throat:	Out of air, can't breathe.
2. Grip partner's wrist or place both hands around waist:	Leave area immediately, no debate.
3. Hands on top of head:	Need assistance.
4. Thumbs Up:	OK, I'm all right. I understand.
5. Thumbs Down:	No, negative.
6. Clenched Fist - Hand Held Up	STOP work, STOP equipment.

3.6 WORK ZONES

One of the basic elements of an effective site control program is the delineation of work zones as described in EPA's Standard Operating Safety Guides, (pg 35). This delineation specifies the type of operations that will occur in each zone, the degree of hazard at different locations within the site, and the areas at the site that should be avoided by unauthorized or unprotected employees. Specifically, the purpose of establishing work zones is to:

- Reduce the accidental spread of hazardous substances by workers or equipment from the contaminated areas to the clean areas;
- Confine work activities to the appropriate areas, thereby minimizing the likelihood of accidental exposure; and
- Facilitate the location and evacuation of personnel in case of an emergency.

Although a site may be divided into as many zones as necessary to minimize an employee's exposure to hazardous substances, the three most commonly identified zones include the support zone, the decontamination zone, and the exclusion zone. A description of each of these zones and the factors to be considered when establishing them are provided below.

Support Zone

The support zones are considered "clean areas" and provide areas or locations where field personnel can take breaks and store field investigation equipment. The support zones also contain site safety and emergency supply equipment (e.g., first aid kits, eye wash units, HASP) and field communication equipment (e.g., mobile phone, walkie talkie). The most important criteria in selection of the support zone is that it lie within an area known to be "clean". The size of the support zone should be commensurate with the extent and type of field activities to be undertaken on the site.

The support zones may consist of the on-site personnel vehicles and/or nearby off-site areas, or a mobile field office trailer. The support zone at the McAllister Point Landfill will consist of the area near a series of concrete foundations present adjacent to the gate entrance to the landfill. Site command vehicles will be parked in this area.

Decontamination Zone

A contamination reduction, or decontamination zone, will be established adjacent to activity-specific exclusion zones. The decontamination zone will be established at the upwind side of the exclusion zone and will consist of a taped off area adequate in size to comfortably contain decontamination equipment. Personnel exiting the exclusion zone shall undergo appropriate decontamination, if required by task-specific procedures described in Section 3.11. A heavy equipment (e.g., drill rig, etc.) decontamination area will be established on-site south of the site support zone, or at another appropriate location neat the site support zone.

Exclusion Zone

Given the relatively limited areas on-site which may be "free" of contamination, activity-specific exclusion zones will generally be established at each boring location/work area at the landfill. During subsurface explorations (e.g., soil borings), the OSC or alternate will establish a 25-foot exclusion zone around the operating equipment (e.g., drill rig) as allowed by area or access constraints. The exclusion zone will be demarcated with caution tape or barricades.

The OSC or alternate will be responsible for keeping nonessential personnel outside the exclusion zone boundaries. In the event that visitors or unauthorized personnel are present during field activities, the OSC or alternate shall verbally request that they maintain a safe distance outside of the area marked by the caution tape and safety cones. Prior to entering the exclusion zone, site personnel shall have donned the proper personnel protective equipment (PPE) for expected site conditions, or as determined by the OSC or alternate.

3.7 SAFETY PROCEDURES

This section describes general safe work practices. The OSC shall assure that standard operating procedures are adhered to, as listed in the EPA Manual "Standard Operating Safety Guides", (EPA, 1992) and the OSHA manual "Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities" (OSHA, 1985).

The following general safety rules will be in effect for potentially hazardous site exploration activities:

- Eating, drinking or smoking will not be allowed in the exclusion or decontamination reduction zone.
- Evidence of unusual site conditions, or previously undetected contaminant source areas (e.g. drums, tanks, etc.) should be immediately reported to the OSC and should not be approached until further information is gathered regarding contents, past use, etc.
- Personal protective equipment specified by this plan shall be worn at all times.
- Personnel entering a site or contaminated area must have the permission of the OSC.
- Report all accidents, injuries, or possible exposures to the OSC immediately.
- Maintain close contact with other site personnel. If PPE is used at the site, check other site workers' PPE periodically to see if it is working adequately.

The OSC will report any chemical release and/or exposures to the TRC Project Manager and Navy representative, if available. Site operations will be conducted in accordance with the general guidelines and procedures outlined in the following publications, which will be available in the site command vehicle on-site:

- <u>Pocket Guide to Chemical Hazards & the 1992-1993 ACGIH Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices</u> - The OSC will utilize information in these publications to establish or modify the necessary levels of personal protection needed on-site. These guides list exposure limits for various chemical compounds, the appropriate protective equipment, and the health hazards associated with accidental exposure.

- The Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities - This publication provides guidance for preparing site-specific health and safety plans. The publication includes information on planning and organization of site operations, incorporating the health and safety plan into the overall hazardous waste operations plan, appropriate training topics, and techniques for characterizing site hazards.

Heavy Equipment

The following guidelines will be applicable to work involving material handling and heavy equipment.

- Pay attention.
- Use common sense.
- Hard hats shall be worn on-site at all times.
- When noise makes verbal communication difficult, hand signals should be used. One person shall be responsible for hand signals given to heavy equipment operators.
- When lifting heavy objects, use the legs, not the back.
- Use appropriate equipment to move heavy objects.
- Only qualified operators shall operate heavy equipment.
- Maintain visual contact at all times.
- Be aware of footing at all times.
- Never walk in the vicinity of heavy equipment without the operator being aware of your presence.
- Be aware of all nearby underground and overhead power, gas, or other utility lines when heavy equipment is used on-site.

3.8 GENERAL HAZARDS

In general, hazards which may be encountered on-site may be classified into three general categories: chemical, physical, and natural. Chemical hazards are area specific and involve potential exposure to chemical contaminants in soil, water, and volatilized components in air. Physical hazards are generally occupationally specific and involve some type of accident. Natural hazards are created by natural environmental circumstances such as weather, poisonous plants, poisonous animals, insect bites, etc.

3.8.1 Physical Hazards

Primary physical hazards which may be encountered at the landfill are those associated with tasks which involve drilling and/or excavation activities. Hazards that could be encountered during subsurface explorations include falls and trips, injury from lifting heavy objects, falling objects, eye injuries, head injuries, and pinched or crushed hands and feet. Electrical hazards may also be present due to both overhead and buried electrical supply lines.

3.8.2 Natural Hazards

Natural hazards such as weather, poisonous plants, animals, and insects cannot always be avoided. Based on available information and site conditions, the site safety officer and field personnel shall use their best judgement to avoid these potential hazards.

Natural hazards include exposure to poisonous plants such as poison ivy and insects such as ticks. TRC personnel will be trained to identify poison ivy and insect repellant will be available in the on-site first aid kits. Special care must be taken to frequently inspect clothing and areas of exposed skin for deer ticks. Deer ticks are minute parasites which are approximately the size of a pin head. These parasites are known to carry Lyme disease, which left untreated, can cause severe respiratory problems, arthritis, and neuromuscular disorders. The OSC will instruct site personnel on deer tick identification and the symptoms of Lyme disease. Insect repellant application, in addition to inspection will be encouraged by the OSC or designee.

Natural hazards also include exposure to adverse weather conditions including heat and cold stress. As indicated in EPA's Standard Operating Safety Guidelines (pg. 93), temperature extremes pose a hazard of particular concern to the health, safety, and comfort of personnel involved in hazardous waste site activities. Site health and safety personnel must consider the two most common dangers, heat stress and cold exposure, when making decisions regarding PPE selection and work mission duration, when establishing standard operating procedures for site activities, and when conducting medical monitoring. Both heat and cold stress are discussed below.

Heat Stress

Heat stress is a potential hazard that will be considered throughout the duration of environmental field activities on-site. Heat stress is magnified by wearing semipermeable and impermeable encapsulating ensembles. Therefore, whenever possible, Level D protection will be maintained, unless air monitoring instruments detect contamination above established background levels or a higher level of protection is warranted by site conditions or specified by the OSC. In addition, if high heat and humidity conditions persist, work activities will be rescheduled to take advantage of the cooler hours of the day. Because heat stress is one of the most common, if not the most serious illnesses at hazardous waste sites, the OSC or his/her designee will institute a monitoring program if the ambient temperature rises above 80°F, and employees are working in Level C protection. The monitoring program may include; heart rate measurement and oral temperature measurements. If heat stress may be a factor due to ambient temperature and humidity, then it is recommended that both methods be used. Also, these tests should be performed in the morning prior to any work to establish a background level. Heart rate monitoring may be conducted as follows:

- Count the pulse rate for the last 30 seconds of the first minute of a three minute period, the last 30 seconds of the second minute, and the last 30 seconds of the third minute.
- Double each count to obtain a equivalent one minute rate.

If the first rate is less than 100 beats/minute and the second two readings are at least 10 beats/minute less than the previous reading then established rest periods should be considered adequate. Otherwise, the rest periods should be extended.

Another method of measuring the effectiveness of the rest periods is to take oral temperatures. If body temperature exceeds 100°F, then the rest periods should be extended. Initially, the frequency of physiological monitoring will depend on the air temperature adjusted for solar radiation and the level of physical work being performed (see ACGIH TLV Guide 1992/3). Level D workers may also be monitored, and work/rest periods strictly adhered to. It should be noted that excessive heat and/or humidity conditions may warrant a work shut-down if the OSC or his/her designee deems that the site temperature conditions are higher than the permissible heat exposure threshold limit value.

To prevent heat fatigue, TRC personnel will be encouraged to maintain an optimal level of physical fitness, and to maintain body fluids at normal levels. To maintain proper cardiovascular function, daily fluid intake must approximately equal the amount of water lost by perspiration and elimination. Generally, the normal thirst mechanism is not sensitive enough to ensure that enough fluid is taken in to replace fluid lost by perspiration. Therefore, TRC workers will be encouraged to drink at least 16 oz. of water before beginning work on hot days. Water or fluids containing essential electrolytes will be readily available to all workers. TRC employees will be urged to drink a cup or two every 15 to 20 minutes or a each monitoring break during periods of heavy physical activity. A total of 1 to 1.6 gallons of fluid per day is recommended, however more may be necessary depending upon individual weight fluctuations and metabolism. TRC will also provide shelter or shaded areas to protect personnel during rest periods.

When protective clothing must be worn, the suggested guidelines are as follows:

Ambient Temperature (°F)	Active Work Time (min/hr) Level A, B, or C Clothing
75 or less	50
80	40
85	30
90	20
95	10
100	0

There are three classes or types of heat stress: heat exhaustion, heat cramps, and heat stroke. Symptoms and treatment techniques for each of these types of heat stress are described below.

Heat Exhaustion

The symptoms of heat exhaustion are:

- General weakness
- Excessive perspiration
- Dizziness
- Appearance of having fainted
- Pale and clammy skin
- Weak pulse
- Rapid and shallow breathing

To treat for heat exhaustion, place the individual in a cool place and remove as much clothing as possible. The individual should drink cool water, "Gatorade" or other similar liquid. The individual should be fanned, however, do not over-cool or allow chilling. Treat the individual for shock and remove to medical facility if condition persists.

Heat Cramps

The symptoms of heat cramps are as follows:

- Pain and cramps in legs or abdomen
- Faintness
- Profuse perspiration

Treatment is similar to that described for heat exhaustion, except that liquids are not given as they may aggravate the condition.

Heat Stroke

The symptoms of heat stroke are:

- Muscle twitching or convulsions
- Dry hot skin
- Flushed skin
- Suddenness of condition
- High body temperature
- Loss of consciousness
- Deep breathing, then shallow or absent
- Dilated pupils

Heat stroke is a serious condition and the individual should be transported to a medical facility as soon as possible. In the interim steps may be taken to reduce the severity of the condition. The individual should be removed to a cool environment and the body temperature should be reduced promptly by dousing the body with water or by wrapping in a wet sheet. If ice is available, it should be placed under arms and around neck and ankles. "Gatorade" or other liquid containing electrolytes should be provided.

Cold Exposure

Cold exposure may result in a lowering of the body temperature due to job-site conditions. Cold exposure and subsequent stress may take the form of hypothermia or frost bite.

The single most important aspect of life-threatening hypothermia (cold stress) is a drop in the deep core temperature of the body. Workers should be protected from exposure to cold so that the deep core temperature does not fall below 36°C (96.8°F). Hypothermia may result in reduced mental alertness, reduction in rational decision making, or loss of consciousness with the threat of fatal consequences.

Pain in the extremities may be the first early warning of danger of frost-bite or cold stress. During exposure to cold, maximum severe shivering develops when the body temperature has fallen to 35°C (95°F). This must be taken as a sign of danger to the workers and exposure to cold should be immediately terminated for workers when severe shivering becomes evident.

Since prolonged exposure to cold air, or to immersion in cold water, at temperatures well above freezing can lead to hypothermia, whole body protection must be provided. Adequate insulating clothing to maintain core temperatures above 36°C must be provided to workers if work is performed in air temperatures below 4°C (40°F). In addition, it should be kept in mind that, the higher the wind speed and the lower the temperature in the work area, the greater the insulation value of the protective clothing required.

Special protection of the hands is required to maintain manual dexterity for the prevention of accidents. The following parameters are extracted from the American Conference of Governmental Hygienists (ACGIH) Threshold Limit Values Booklet for 1992-93:

1. If fine work is to be performed with bare hands for more than 10-20 minutes in an environment below 16°C (60°F), special provisions should be established for keeping the workers' hands warm. For this purpose, warm air jets, radiant heaters, or contact warm plates may be utilized. Metal handles of tools and control bars should be covered by thermal insulating material at temperatures below -1°C (30°F).

2. If the air temperature falls below 16°C (60°F) for sedentary, 4°C (40°F) for light, -7°C (20°F) for moderate work and fine manual dexterity is not required, then gloves must be used by the workers. To prevent contact frostbite, the workers should wear gloves.

Provisions for additional body protection is required if work is performed in an environment at or below 4°C (40°F). The workers shall wear cold protective clothing appropriate for the level of cold and physical activity to be undertaken:

1. If the air velocity at the job sites is increased by wind, draft, or artificial ventilating equipment, the cooling effect of the wind shall be reduced by shielding the work area, or by wearing an easily removable outer windbreak layer garment.

2. If only light work is involved and if the clothing on the worker may become wet on the job site, the outerlayer of the clothing should be of a type impermeable to water. With more severe work under such conditions, the outer layer should be water repellent and the outerwear should be changed as it becomes wetted. The safety coordinator should assure that adequate replacement garments are available for use by TRC employees.

3. If available clothing does not provide adequate protection to prevent hypothermia or frostbite, the safety coordinator may suspend work on the site until adequate clothing is available or until weather conditions improve.

4. Workers handling evaporative liquids (gasoline, alcohols, solvents, etc.) at air temperatures below 4°C (40°F) shall take special precautions to avoid soaking of clothing or gloves with the liquids because of the added danger of cold injury due to evaporative cooling.

TRC will provide its employees with cold weather outer clothing (e.g. coveralls, etc.) as necessary. However, individuals are encouraged to supplement this clothing for additional cold protection at their discretion.

3.8.3 Site Specific Chemical Hazards

Historical information indicates that the McAllister point Landfill was used for the disposal of wastes, including spent acids, paints, solvents, oils, and PCB-contaminated oils. The findings of the Phase I RI indicate the presence of elevated concentrations of volatile organic compounds (VOCs), polynuclear aromatic hydrocarbons (PNAs), and metals in site soils. The highest levels of VOCs, PNAs, and metals were generally detected in the central and southern portion of the site.

Fill is present across the site at depths ranging from approximately three feet at the site periphery to 24 feet in the central portion of the landfill. The fill material encountered during Phase I explorations consisted of an assortment of what appeared to be municipal and industrial waste (e.g., plastic, wood, paper, garbage, construction debris, paints, ash). Elevated levels of VOCs and metals were detected in site ground water. PCBs were also detected within a well (MW-5S) at the southern portion of the landfill where free product (oil) was observed. Previous investigations also showed levels of metals, petroleum hydrocarbons, and PCBs in adjacent bay sediments; and elevated concentrations of metals in adjacent bay mussels. A list of the Phase I identified contaminants of concern are provided on Table 2.

The potential for exposure to site contaminants could result from inhalation, ingestion, or direct contact (skin absorption) with soils or waters contaminated with VOCs, PNAs or metals.

3.8.4 Hazard Communications Plan

The site hazard communications plan is intended to augment the site communications procedures described in Section 3.5.1. The hazard communications plan consists of a series of periodic meetings and/or briefings to update site personnel on the most current information on site conditions, levels of PPE to be used, and other factors necessary to achieve project objectives and protect the safety and health of site workers.

Health and Safety Site Orientation

All site investigation personnel shall be required to read this HASP and attend the Health and Safety Site Orientation meeting. Documentation of attendees will be maintained as part of project records. The HASP will accompany field personnel to the site and shall be maintained at a location known to each individual working on-site.

The Project Manager or OSC will conduct a health and safety site orientation prior to the initiation of field activities. The orientation will cover all aspects of this HASP. Particular emphasis will be placed on a review of potential site contaminants and their potential health effects; accident prevention; safe work procedures; precautionary measures; use of personnel protective equipment; and emergency response procedures. Field staff are required to attend.

Health and Safety Briefings

The OSC or alternate will conduct a Health and Safety Briefing on a routine basis. Topics to be covered include personnel protective equipment, personnel and equipment decontamination procedures, accident prevention, and any modifications or amendments to the Health and Safety Plan. Field staff are required to attend. A Safety Meeting Summary Form documenting personnel attending each meeting will be maintained in project files.

3.9 LEVELS OF PERSONAL PROTECTIVE EQUIPMENT

Given the nature of work activities at contaminated sites, the use of personal protective equipment (PPE) is intended to shield employees from exposure to hazardous and/or toxic substances. The two basic objectives of a PPE selection program are to protect the wearer from safety and health hazards, and to prevent injury to the wearer from incorrect use and/or malfunction of the PPE. Since different levels of protective gear are needed at individual sites, EPA has established four basic levels of protection; Level A, B, C, and D. The following description of PPE protective levels was extracted from EPA's Standard Operating Safety Guides, 1992.

Level A

Level A protection is required when the greatest potential for exposure to site hazards exists, and when the greatest level of skin, respiratory and eye protection is required. Meeting any of the following criteria warrants use of level A protection:

- Hazardous substances have been identified and require the highest level of protection for skin, eyes, and the respiratory system;
- The atmosphere contains less than 19.5 percent oxygen;
- Site operations involve a high potential for splash, immersion, or exposure to unexpected materials that are harmful to the skin;
- Operations are being conducted in confined, poorly ventilated, and the absence of hazardous substances has not yet been determined; or
- Direct-reading instruments indicate high levels of unidentified vapors or gases in the air.

In addition it may be necessary to base the decision to use level A PPE based on indirect evidence. Other conditions that may indicate the need for Level A protection include:

- Confined spaces;
- Suspected or known highly toxic substances, especially when field equipment is not available to test site concentrations; and
- Visible indicators such as leaking containers or smoking chemical fires.

The use of level A PPE equipment is not anticipated for design-phase field exploration activities at the McAllister Point landfill.

Level B

Level B protection is required under circumstances requiring the highest level of respiratory protection, with a lesser level of skin protection. If any of the following criteria are met, the use of Level B protection may be warranted:

- The type and atmospheric concentration of substances have been identified and require a high level of respiratory protection, but less skin protection than needed for Level A;
- The atmosphere contains less than 19.5 percent oxygen; or
- The presence of incompletely identified vapors and gases is indicated but they are not suspected of being harmful to the skin.

The use of Level B protection does not afford as great a level of protection to the skin and eyes as Level A, but it does provide a high level of respiratory protection. At most outdoor sites, ambient vapor or gas levels are not typically high enough to warrant Level A protection. Level B protection is often adequate.

Although not anticipated to be used on-site, Level B protective equipment generally includes the following:

- Hard Hat
- Chemically-resistant steel-toe and shank boots
- Disposable Tyvek coveralls with hood (coated for aqueous sampling)
- Inner and outer gloves (vinyl and neoprene, respectively)
- Positive pressure type self-contained breathing apparatus

Level C

Level C protection is required when the concentration and type of airborne substances is known, and the criteria for using air purifying respirators is met. Meeting any of the following criteria warrants use of Level C protection:

- The atmospheric contaminants, liquid splashes or other direct contact will not adversely affect or be absorbed by the skin;

- The types of air contaminants have been identified, concentrations do not exceed IDLH levels, and an air-purifying respirator is available that can remove the contaminants; and

- Oxygen concentrations are not less than 19.5% by volume, and job functions do not require SCBA.

Level C protection is distinguished from Level B by the equipment used to protect the respiratory system, assuming the same type of chemical-resistant clothing is used. The main selection criteria for Level C is that atmospheric concentrations and other selection criteria permit wearing an air-purifying respirator.

In general, Level C protective equipment which will be used at the site includes the following:

- Hard Hat
- Chemically-resistant steel-toe and shank boots
- Disposable Tyvek coveralls with hood (coated for aqueous sampling)
- Inner and outer gloves (vinyl and neoprene, respectively)
- Full-face respirator with organic vapor cartridges and dust mist, and fume pre-filter.

Level D

Level D is the minimum protection required. This level of protection is sufficient under the following conditions:

- No contaminants are present, or they are present at concentrations below 8-hour TLV levels; or

- Work operations preclude the potential for splashes, immersion, or the inhalation of hazardous or toxic substances.

In general, Level D protective equipment which will be used at the site includes the following:

- Hard Hat
- Chemically-resistant steel-toe and shank boots
- Disposable Tyvek coveralls with hood (coated for aqueous sampling)
- Inner and outer gloves
- Safety Goggles or splash-shield (only for aqueous sampling).

Specific work activities and initial levels of protection are discussed in Section 3.11.

3.10 MONITORING REQUIREMENTS

A specifically designated person will be assigned the task of continuously monitoring for organic vapor emissions during subsurface exploration activities. This person will use a flame or photo-ionization detection (FID or PID) device such as an HNU or the Century OVA, and LEL/O_2 meters (or equivalent) simultaneously for measuring potentially hazardous atmospheres. The OVA, a flame ionization detection (FID) device, will be calibrated to hydrocarbon free air and a known hydrocarbon once per day according to the procedures in TRC Technical Standards T/S-990, Operation and Calibration of the Century Organic Vapor Analyzer Model OVA-128. The LEL Meter will be calibrated once per day using Pentane (0.75% by volume in air) according to TRC T/S-991. Operation and Calibration of the MSA Model 260 Combustible Gas and Oxygen Alarm Meter. Both meters will provide real time readings, and a log will be kept of these readings throughout the course of the environmental investigations.

If airborne concentrations of flammable vapors exceed 10% of the lower explosive limit (LEL) at the point of subsurface explorations no ignition sources will be permitted in the area. Operations will be suspended, and corrective action taken (backfilling of the hole) if the airborne flammable concentration reaches 25% of the LEL at a distance of one foot from the point of drilling or 10% of the LEL at a distance of greater than two feet.

3.10.1 Action Levels

The OSC shall use air monitoring equipment identified above (or equivalent) to monitor organic vapors in the breathing zone at the upwind boundary of the Exclusion Zone at the beginning of each day, to establish a daily background reading.

The federal regulation 20 CFR Part 1910.120 (h)(2-3) indicates air monitoring is required upon initial entry of the exclusion zone, and periodic monitoring shall be conducted when the possibility of an immediately dangerous to life and health (IDLH) condition exists or when there is an indication that exposures may have risen over permissible or published limits since prior monitoring. The air monitoring program which will be established at individual work areas on-site is intended to be consistent with these requirements.

The following general action levels are based on PID/FID breathing zone readings:

- 0 to 5 units above background: Level D
- 5 to 25 units above background for longer than one minute: Level C
- 25 units or greater for longer than one minute: discontinue operations. Make arrangements to continue work in Level B protective equipment or use Level B to retrieve/demobilize equipment.

The OSC may also make the decision to upgrade the PPE requirements, even if positive PID/FID readings are not noted. This decision will be based on site conditions including visual or sensory observation of soil or ground water contamination, or other site hazards.

3.11 ACTIVITY SPECIFIC HEALTH AND SAFETY PROCEDURES

Activity-specific health and safety procedures are outlined in this section for two remedial design site activities; general site procedures, and subsurface explorations. A list of pre-design activities, suspected health risks and initial and backup PPE levels are provided on Table 3.

Modifications may be made to this HASP as site conditions vary, either naturally or through the activities of the remedial investigation team. The plan may also need to be modified as more detailed information about the site and its potential hazards becomes available. These changes will be initiated by the OSC or Project Manager and will be reviewed and approved by the Site Safety Director or his designee. Any modifications will be clearly marked on the on-site copy of the HASP and explained to field personnel.

3.11.1 General Site Activities

Chemical and Physical Hazards

Site-specific activities which do not involve subsurface explorations (e.g. site reconnaissances, land surveys, etc.) could result in the exposure of workers to contaminated surface soils or vapors. Such an occurrence can lead to worker exposure via inhalation or permeation through the skin (skin absorption). However, in general, non-invasive activities do not require direct contact with site soils and/or waters, and therefore exposures are anticipated to be minimal.

Monitoring

The OSC shall use a photoionization detector (PID) or flame ionization detector (FID) to monitor organic vapors in the breathing zone at the upwind boundary of the Exclusion Zone at the beginning of each day, to establish a daily background reading.

The federal regulation 20 CFR Part 1910.120 (h)(2-3) indicates air monitoring is required upon initial entry, and periodic monitoring shall be conducted when the possibility of an immediately dangerous to life and health (IDLH) condition exists or when there is an indication that exposures may have risen over permissible or published limits since prior monitoring. The air monitoring program conducted for general site activities is intended to be consistent with these requirements.

Action Levels

Field work for general site activities will be initiated in Level D personnel protective gear for those areas which background surface soil data indicates a low potential worker risk under normal conditions. Based on the PID/FID readings in the breathing zone, or site conditions, the OSC shall upgrade or downgrade PPE requirements as described below.

The following action levels are based on breathing zone readings:

- 0 to 5 units above background: Level D

- 5 to 25 units above background: Level C

- 25 units or greater: discontinue operations. Make arrangements to continue work in Level B protective equipment or use Level B to retrieve/demobilize equipment.

The OSC may also make the decision to upgrade the PPE requirements, even if positive PID/FID readings are not observed. This decision will be based on site conditions including visual or sensory observation of soil or ground water contamination, or other site hazards.

Personnel Protective Equipment (PPE)

This section contains specific provisions for the use of Personnel Protective Equipment (PPE). It shall be the responsibility of the OSC to make the determination of the level of PPE to be used by personnel within the Exclusion Zone. The decision of the OSC will be based on previous environmental data and knowledge of the landfill, site monitoring, action levels, and observed site conditions. Changes affecting the level of PPE defined in the HASP will be at the direction and approval of the Project Manager and/or Director of Health and Safety, except in the case of an emergency during which time it will be the responsibility of the On-Site Coordinator to modify PPE levels.

Level D protection shall be used at the start of most field work. Level D protection shall include use of the following items:

- work clothes;
- hard hat;
- work boots; and
- chemical protective gloves when collecting soil and water samples (solvex/nitrile).
- inner glove liners (latex/vinyl)

Level D protection may also include the use of a polycarbonate faceshield, attached to the hard hat, in the event that potential splash conditions are present. Use of the splashguard shall be at the discretion of the OSC.

An upgrade to Level C may be necessary if the concentration of VOCs detected in the breathing zone of the workers exceeds the action level of 5 PID/FID units, or if warranted by other site conditions. Level C protection will include all of the PPE required for Modified Level D plus appropriate respiratory protection. The specific respirator to be used for Level C protection shall be a NIOSH-approved respirator with compatible cartridges. Respirator cartridges will be changed at the first sign of break through, or daily at a minimum, when in use.

Decontamination

Upon leaving the Exclusion Zone, personnel must undergo appropriate decontamination. The nature of the decontamination requirements will depend on the nature of the work conducted and whether immediate re-entry into the Exclusion Zone is planned, or if complete egress from the Exclusion Zone is intended.

The personnel decontamination requirements will also depend on the level of protection used within the Exclusion Zone and the suspected degree of contamination. This area will be located immediately outside the access opening of the Exclusion Zone on its apparent upwind side. This area shall contain the decontamination stations necessary to allow rest breaks and respirator cartridge changes (if appropriate), as well as for complete decontamination as required for food and beverage breaks, or exiting the work area. Periodic air monitoring will be conducted in the contamination reduction zone (decontamination area) when this area is used.

Equipment decontamination will occur within the decontamination or contamination reduction zone at each area. The following list outlines procedures to be employed for personnel and equipment decontamination.

Level D - Personnel Decontamination Procedures - 9 Station

Level D - Station 1: Segregated Equipment Drop

Deposit equipment used on-site (tools, sampling devices and containers, monitoring instruments, radios, clipboards, etc.) on plastic drop cloths or in different containers with plastic liners. Segregation at the drop station reduces the probability of cross-contamination. During hot weather operations, cool down stations may be set-up within this area.

Level D - Station 2: Outer Glove Removal

Remove outer gloves and deposit in a container with a plastic liner.

Level D - Station 3: Tyvek Removal:

With assistance of a helper, if needed, remove Tyvek coveralls. Deposit in a container with a plastic liner.

Level D - Station 4: Inner Glove Wash:

Wash inner gloves with a decon solution.

Level D - Station 5: Inner Glove Rinse:

Rinse inner gloves with water.

Level D - Station 6: Inner Glove Removal:

Remove inner gloves and deposit in a container with a plastic liner.

Level D - Station 7: Inner Clothing Removal (as needed):

Remove clothing soaked with perspiration and place in a plastic-lined container.

Level D - Station 8: Field Wash (as needed):

Shower if highly toxic, skin corrosive or skin absorbable materials are known or suspected to be present. Wash hands and face, don't forget to wash behind your ears.

Level D - Station 9: Re-Dress (as necessary):

Put on clean clothes.

Level C - Personnel Decontamination Procedures - 16 Station

Level C - Station 1: Segregated Equipment Drop

Deposit equipment used on-site (tools, sampling devices and containers, monitoring instruments, radios, clipboards, etc.) on plastic drop cloths or in different containers with plastic liners. Segregation at the drop station reduces the probability of cross-contamination. During hot weather operations, cool down stations may be set-up within this area.

Level C - Station 2: Boot/Boot Cover and Glove Wash

Scrub outer boot covers and gloves with decon solution or detergent water.

Level C - Station 3: Boot/Boot Cover and Glove Rinse:

Rinse off decon solution from Station 2 with clean water.

Level C - Station 4: Tape Removal:

With assistance of a helper, if needed, remove tape from around boots and gloves and deposit in a container with a plastic liner.

Level C - Station 5: Boot Cover Removal:

Remove boot covers and deposit in a plastic lined container.

Level C - Station 6: Outer Glove Removal:

Remove outer gloves and deposit in a container with a plastic liner.

Level C - Station 7: Canister or Mask Change:

If worker leaves exclusion zone to change canister (or mask), this is the last step in the decontamination procedure. Workers canister is exchanged, new outer gloves and boot covers donned, and joints taped. Worker returns to duty.

Level C - Station 8: Safety Boot Removal:

Remove safety boots and place in area with plastic liner.

Level C - Station 9: Tyvek removal:

Remove equipment which would hinder Tyvek removal (i.e. SCBA air tanks, re-breather packs, etc.). With the assistance of a helper if needed, remove Tyvek. Deposit in a container with plastic liner.

Level C - Station 10: Inner Glove Wash:

Wash inner gloves with decon solution.

Level C - Station 11: Inner Glove Rinse:

Rinse inner gloves with water.

Level C - Station 12: Respirator Removal:

Remove respirator. Deposit in a container with a plastic liner. Avoid touching face with fingers.

Level C - Station 13: Inner Glove Removal:

Remove inner gloves and deposit in a container with a plastic liner.

Level C - Station 14: Inner Clothing Removal (as needed):

Remove clothing soaked with perspiration and place in a lined container.

Level C - Station 15: Field Wash (as needed):

Shower if highly toxic, skin corrosive or skin absorbable materials are known or suspected to be present. Wash hands and face.

Level C - Station 16: Re-Dress (as necessary):

Put on clean clothes.

The personnel decontamination procedures for Level B protection are the same as for Level C except Station 7 (where the word air tank is exchanged for canister) and Station 12 (where the word respirator is changed to a self contained breathing apparatus (SCBA)).

3.11.2 Subsurface Exploration Activities

This section describes the health and safety considerations for subsurface exploration activities. Such activities would include site borings and vapor probe installations.

Chemical and Physical Hazards

Subsurface exploration activities may result in the exposure of workers to potentially contaminated soils and ground water, washwater from decontamination of heavy equipment, and vapors released from contaminated site media. Such an occurrence can lead to worker exposure via inhalation, ingestion, and permeation through the skin (skin absorption).

Monitoring

The OSC shall use a PID or FID to:

- Monitor organic vapors in the breathing zone at the upwind boundary of the Exclusion Zone at the beginning of each day, to establish a daily background reading.
- Monitor organic vapors in the worker's breathing zone during active subsurface explorations.
- Monitor the workers breathing zone at fifteen-minute intervals or continuously during active subsurface explorations, if elevated levels of organic vapors are detected.

Other monitoring equipment will include an combustible gas/oxygen meter to monitor the ambient air and downhole or pit vapors to monitor for explosive vapors and oxygen content.

Action Levels

Unless otherwise determined by the OSC, Modified Level D protection shall be used at the start of subsurface exploration tasks. Based on positive PID/FID readings in the breathing zone or site conditions, the OSC shall upgrade Personnel Protective Equipment (PPE) requirements, as appropriate.

Action levels to be used for subsurface exploration activities are outlined in Section 3.11.1. Additional action levels for the combustible gas/oxygen meter are as follows:

A. If airborne concentrations of flammable vapors exceed 10 percent of the lower explosive limit (LEL), no ignition sources will be permitted in the area.

B. If ambient conditions exceed 25 percent of the LEL at a distance of one foot from the source, or ten percent at a distance of two feet or greater, then site operations will be halted and appropriate corrective actions (upgrade of PPE, use of blowers or other response equipment or abandonment of the exploration) will be taken.

Personnel Protective Equipment (PPE)

Based on site conditions and action levels described above, the OSC shall upgrade or downgrade personnel protective requirements commensurate with site hazards. The OSC may also make the decision to upgrade the PPE requirements, even if positive PID requirements are not noted. This decision will be based on site conditions including visual or sensory observations of potential contamination.

During subsurface exploration activities and well installation activities, an upgrade to Modified Level D protection may be required. Necessary equipment for Modified Level D protection will include that of Level D plus the additional PPE listed below:

- chemically resistant boots, PVC/rubber overboots, or disposable boot covers;
- Tyvek or equivalent jump suit (with ankles and wrists duct taped);
- chemically protective outer gloves (solvex/nitrile); and
- inner glove liners (latex/vinyl).

If odorous soils are detected during subsurface explorations the following procedures will be employed:

- if PID or FID readings of auger spoils are consistently above 5 PID units, the air monitoring frequency will be increased; and,

- a change, if necessary, to the appropriate PPE will occur.

Exclusion Zone

In recognition of the increased risk of physical injury and exposure to chemical contaminants during subsurface investigation activities, an exclusion zone of a minimum of approximately 25 feet shall be established around exploration equipment (i.e., drill rig, backhoe). Nonessential personnel shall be prohibited from entering the exclusion zone. All personnel entering the exclusion zone will be required to wear appropriate personnel protective equipment.

Decontamination

A separate area will be designated for the decontamination of heavy equipment. A steam generator will be used to clean the under-carriage, wheels, track, and drill derrick between borings, as necessary. A shallow pit will be dug and lined with two 10 to 12 mil thick, nylon reinforced polyethylene plastic tarps where the vehicles will be parked during decontamination operations.

To minimize spreading potentially contaminated soil, a gross decontamination of the downhole tools and rig will take place at the individual sites prior to transporting them to the decon area. This will involve on-site removal of loose soil from the tools and rig, and containerizing tools in the back of a truck (e.g. wrap in plastic) while transporting them to the decon pit.

An attempt will be made to coordinate an exploration sequence hierarchy from less likely to more likely contaminated locations to reduce the potential for cross-contamination between locations. Decontamination rinsates will be collected and contained in drums for subsequent determination of proper handling and/or disposal as described in the Investigation-Derived Waste Plan provided as Appendix B.

3.12 EMERGENCY INFORMATION

Prior to commencing site operations, the TRC OSC will review and communicate general emergency preparedness and planning procedures to on-site personnel. Such procedures will include a discussion of evacuation and rescue plans/routes, emergency assistance, and the location of site communication and emergency (e.g. first aid) equipment.

The Newport Hospital is the closest medical facility other than the emergency services available through the NETC Fire/Ambulance Department. A map indicating the location and likely quickest route to this center is provided as Figure 8.

3.12.1 Emergency Response Plan

All hazardous waste site activities present a degree of risk to on-site personnel. During routine operations, risk is minimized by establishing good work practices, staying alert, and using proper personnel protective equipment. Unpredictable events such as physical injury, chemical exposure, or fire may occur and must be anticipated.

Emergency conditions are considered to exist if:

- Any member of the field crew is involved in an accident or experiences any adverse effects or symptoms of exposure while on-site; or

- A condition is discovered that suggests the existence of a situation more hazardous than anticipated.

Prior to conducting field work, the TRC Project Manager and OSC will implement the following general emergency/safety procedures. The implementation will consist of including the following considerations in project planning, as well as site-specific briefing sessions for field team members.

- In the event of an emergency, the TRC and NETC emergency contacts identified in Table 4 shall be notified. A list containing emergency service phone numbers and a route map to the closest medical facility will be posted conspicuously and will be readily available at the site.

- Personnel on-site should use the "buddy"system (e.g. work in pairs). Buddies should prearrange hand signals or other means of emergency signals for communication in case of lack of, or trouble with, site communication equipment.

- Visual contact should be maintained between personnel on-site. Field teams will remain in close proximity to assist each other in case of emergencies.

- TRC field crews will use FM radios to maintain routine communication and for emergencies.

- In the event that a member of the field crew experiences adverse effects or symptoms of exposure while on the scene, the entire field crew should immediately halt work and act according to the instructions of the OSC.

- The discovery of any condition that would suggest the existence of a situation, or task, more hazardous than anticipated should result in a cessation of work activities at the site. The situation or task may then be re-evaluated and the level of personnel protection modified, if necessary, prior to resuming work.

- In the event that an accident occurs, the OSC will complete an Accident Report Form (see Appendix E). The project manager will be notified and appropriate action will be taken by the OSC to correct the situation that caused the accident.

- Field crew members must stay alert to evidence of potentially hazardous conditions such as strong or irritating odors or evidence of the presence of buried wastes (e.g. drums, etc.).

- Personnel should practice unfamiliar operations prior to performing the actual procedure in the field.

- Field crew members shall be familiar with the physical characteristics of the site, including:
  - wind direction in relation to contaminated areas;
  - accessibility to associates, equipment, vehicles, and communication equipment;
  - exclusion zones;
  - site access restrictions;
  - nearest water source.

- Personnel and equipment in the contaminated area shall be kept to the minimum requirements necessary to complete the task-at-hand.

Roles of Personnel in Emergencies

The TRC OSC or designee will always be on-site, or will be available immediately by telephone or FM radio. The OSC will take appropriate action to ensure efficient and expeditious handling of emergency situations.

Specific roles of personnel at the site include the following:

- Site workers - use "buddy" system and follow procedures outlined in this plan. Contact OSC immediately if an emergency arises.
- OSC - role as described above.
- NETC or NORTHDIV OSC - work with TRC OSC at start of project to develop emergency response procedures. Coordinate NETC or Navy personnel and contractor personnel, if appropriate, in responding to the emergency.
- TRC Project Manager - ensure emergency response procedures outlined in this plan receive high priority ,and are effectively implemented.
- TRC Health and Safety Director - work with project manager and OSC to provide support as needed.

3.12.2 Emergency Response Plan - Specific Incidents

First Aid - General

All injuries, no matter how slight, shall be reported to the OSC immediately. A TRC accident report form (Appendix E) will be filled out for all accidents. Project personnel will be instructed on the location of the first aid station, hospital, doctor and ambulance service near the job. The emergency phone numbers will be conspicuously posted in the site trailer. First aid supplies will be available in the site command vehicle on-site. At those areas where a restricted zone is established, the supplies will be located between restricted and non-restricted areas so as to be readily accessible to all site personnel.

Medical advice and procedures directed by doctors, nurses, and first aid attendants will be followed. No person shall attempt treatment of injuries except as directed below for burns or for injuries requiring immediate attention.

Burns

Immediately treat acid, caustic and thermal burns by rinsing in cold water, then report promptly to the OSC, or designee. Movement of injured persons will be avoided unless the injured person is in immediate danger.

Chemical Exposures

Exposure to chemicals may be divided into two general categories:

- Injuries from direct contact, such as acid burns or inhalation of toxic chemicals; and
- Potential injury due to gross contamination on clothing or equipment.

For inhaled contaminants, treatment shall be by qualified physicians. If the contaminant is on the skin or in the eyes, immediate measures must be taken to counteract or dilute the substance's effects. First aid treatment usually includes flooding the affected area with water for at least 15 minutes; however, for a few chemicals, water may cause more severe problems.

When protective clothing is grossly contaminated, contaminants may be transferred to treatment personnel or the wearer and cause injuries. Appropriate precautions (e.g. wrap contaminated person in a blanket) will be taken to protect emergency personnel for contaminants, as warranted.

Physical Injury

Physical injuries can range from a sprained ankle to a compound fracture, from a minor cut to massive bleeding. Depending on the seriousness of the injury, treatment may be given at the site by trained response personnel. For more serious injuries, additional assistance may be required on-site or the victim may have to be treated at a medical facility.

Life-saving care should be instituted immediately for physical injuries without consideration of personnel decontamination. The outside garments can be removed if they do not cause delays, interfere with treatment, or aggravate the problem. Respirator assemblies must always be removed. Chemical-resistant clothing can be cut away.

For non-life threatening cases, the individual should be wrapped in plastic, rubber, or blankets to help prevent contaminating medical personnel and the inside of the ambulance. Outside garments are then removed at the medical facility. No attempt should be made to wash or rinse the victim at the site. One exception would be if it is known that the individual has been contaminated with an extremely toxic or corrosive material which could also cause severe injury to emergency personnel. For minor medical problems or injuries, the normal decontamination procedure should be followed.

Emergency Decontamination

Emergency decontamination procedures include the following:

- Another team member shall remove the individual from the immediate area of contamination.
- Precautions shall be taken to avoid exposure of emergency personnel to the chemical.
- If contaminants are on the individuals clothing, the clothing shall be removed, if it is safe and prudent to do so.
- If the contaminant has contacted the skin, the skin shall be washed with copious amounts of water, preferably under a shower for at least 15 minutes.
- In case of eye contact with the contaminant, an emergency eye wash apparatus shall be used.
- If necessary, the victim shall be transported to the nearest hospital or medical center. If necessary, an ambulance will be called to transport the victim.
- All chemical exposure incidents will be reported in writing by the OSC on an Accident Report Form (see Appendix E).

Under certain circumstances, decontamination may aggravate or cause more serious health effects. If prompt life-saving first aid and medical treatment is required, decontamination procedures will be omitted. Whenever possible, TRC personnel shall accompany contaminated victims to the medical facility to advise medical personnel on matters involving the nature of the exposure.

4.0 EVALUATION OF ARARS

4.1 INTRODUCTION

A description of the cap at the McAllister Point Landfill is provided below prior to identifying the ARARs applicable to the design of a cap.

As described in the final McAllister Point Proposed Plan a multi-layer cap would be placed over the landfill area to limit the amount of infiltration and thereby minimize leachate production. The cap would cover approximately 10.5 acres, encompassing the landfill area at McAllister Point, including identified areas of ash, construction debris and domestic waste disposal. The cap would be designed to meet or exceed Resource Conservation and Recovery Act (RCRA) guidance as described in the USEPA documents, Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments (USEPA, 1989) and Design and Construction of RCRA/CERCLA Final Covers (USEPA, 1991), and in accordance with accepted engineering design practices. Site-specific factors will be considered in determining an effective cap design. A typical cover system is composed of a vegetative and protective layer, a drainage layer, an upper barrier layer consisting of a synthetic membrane, and a lower barrier layer consisting of a low permeability soil barrier. An optional gas vent layer may be placed below the lower barrier layer, if determined to be appropriate during the landfill gas management system evaluation.

4.2 ARARs IDENTIFICATION AND ANALYSIS

This remedy will attain all Applicable or Relevant and Appropriate federal and state requirements (ARARs) that apply to the McAllister Point Landfill site and this remedial action. Environmental laws from which ARARs for the selected source control remedial action are derived, and the specific ARARs are summarized below.

4.2.1 Chemical-Specific ARARs

No chemical-specific ARARs are applicable to the selected remedial action.

4.2.2 Location-Specific ARARs

- Executive Order 11988 and 11990; Statement on Proceedings of Floodplain Management and Wetlands Protection (40 CFR 6, Appendix A)

- Clean Water Act Section 404 (40 CFR 230.10) Requirements for Discharge of Dredge of Fill Material

- Rivers and Harbors Act (Section 10) Prohibition of Filling a Navigable Water

- Fish and Wildlife Coordination Act of 1958 (16 U.S.C. 661) Protection of Wildlife Habitats

- Endangered Species Act of 1973 (16 U.S.C. 1531) Protection of Endangered Species

- National Historic Preservation Act of 1966 (16 U.S.C. 470, et seq.) Protection of Historic Lands and Structures

- Archaeological and Historic Preservation Act of 1974 (132 CFR 229 & 229.4, 43 CFR 7 & 7.4); Historic Sites, Building and Antiquities Act

- Rhode Island Wetlands Laws (RIGL 2-1-18 et seq.); Rhode Island Department of Environmental Management Rules Governing the Enforcement of the Freshwater Wetlands Act - as amended Dec. 21, 1986

- Rhode Island Coastal Resources Management Law (RIGL, Title 46, Chapter 23) and Regulations

4.2.3 Action-Specific ARARs

- RCRA (40 CFR 264) Subtitle C Requirements:

  - 40 CFR 264.10-264.18 Subpart B - General Facility Standards
  - 40 CFR 264.30-264.37 Subpart C - Preparedness and Prevention
  - 40 CFR 264.50-264.56 Subpart D - Contingency Plan and Emergency Procedures
  - 40 CFR 264.90-254.101 Subpart F - Ground Water Protection
  - 40 CFR 264.110-118 Subpart G - Closure/Post Closure Requirements
  - 40 CFR 264.301-264.310 Subpart N - Landfill Requirements

- Migratory Bird Treaty Act (16 U.S.C. 703-712)

- Clean Water Act Section 404 (40 CFR 230.10) Requirements for Discharge of Dredged or Fill Material

- Rivers and Harbors Act (Section 10) Prohibition of Wetland Filling

- Clean Air Act:
  - Section 5 171 through 178, 42 USC §§ 7471-7478 (Requirements for Non-Attainment Areas)
  - Section 5 160 through 169A - Prevention of Significant Deterioration Provisions

- Clean Water Act (40 CFR 122-125) National Pollutant Discharge Elimination System (NPDES) Permit Requirements

- RI Hazardous Waste Management Act of 1978 (RIGL 23-19.1 et seq.) Hazardous Waste Management Rules and Regulations and Proposed Amendments:

  - Section 7
  - Section 8
  - Section 9
  - Section 10

- RI Clean Air Act (RIGL, Title 23, Chapter 23) General Air Quality and Air Emissions Requirements
  - RI Air Pollution Control Regulations, RI Dept. of Health, Div. of Air Pollution Control, effective 8/2/67, amended 5/20/91
    - Regulation No. 1 - Visible Emissions
    - Regulation No. 5 - Fugitive Dust
    - Regulation No. 7 - Emissions Detrimental to Person or Property
    - Regulation No. 15 - Control of Organic Solvent Emissions
    - Regulation No. 17 - Odors
    - Regulation No. 22 - Air Toxics

- RI Water Pollution Control Act
  - RI Water Quality Regulations for Water Pollution Control (RIGL 46-12 et seq.)
  - RI Regulations for the Pollutant Discharge Elimination System (RIPDES) (RIGL 46-12 et seq.)

The following action-specific policies, criteria and guidelines were also considered:

- RCRA Proposed Rule 52 FR 8712 - Proposed Amendments for Landfill Closures

- EPA Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments (EPA 530-SW-89-047)

- Clean Air Act (40 CFR 50) New Source Performance Standards (NSPS) Proposed Subpart WWW 56 FR 24468-24528 (5/30/91)

- Clean Air Act (40 CFR 61) National Emissions Standards for Hazardous Pollutants (NESHAPS)

Federal Location-Specific Regulations - The federal location-specific regulations that apply to the selected remedy are mainly based on the site's location adjacent to Narragansett Bay. Executive Orders 11988 and 11990 require the avoidance, wherever possible, of long- and short-term impacts associated with the destruction of wetlands and the occupancy and modifications of floodplains and wetlands whenever there is a practicable alternative. Similarly, Section 404 of the Clean Water Act prohibits the discharge of dredged or fill material to a water of the United States if there is a practicable alternative which poses less of an adverse impact or if it causes significant degradation of the water. The Rivers and Harbors Act prevents filling of a navigable water. The Fish and Wildlife Coordination Act of 1958 requires consultation with federal and state conservation agencies during planning and the decision-making process for any action which may impact water bodies, including wetlands, as well as consideration of prevention, mitigation or compensation measures. These standards are applicable to cap construction and slope protection activities which impact wetland, floodplain or coastal areas. Remedial designs will be developed to minimize adverse impacts to these areas. If adverse impacts to wetland areas cannot be avoided as part of the selected remedy, appropriate mitigating actions will be taken.

The Endangered Species Act of 1973 is a potential ARAR for activities which could impact endangered or threatened wildlife species. An environmental assessment conducted during the Phase II RI, prior to cap construction, will determine if endangered species inhabit the site. The National Historic Preservation Act of 1966 and the Archaeological and Historic Preservation Act of 1974 govern the preservation of historic, scientific and archaeological sites. Remedial actions must be coordinated with preservation agencies and societies to minimize loss of significant scientific, prehistoric, historic or archaeological data.

State Location-Specific Requirements - The state location-specific regulations that apply to the selected remedy are based on the site's location adjacent to Narragansett Bay. The Rhode Island Wetlands Laws define and establish provisions for the protection of swamps, marshes and other freshwater wetlands. The Rhode Island Coastal Resources Management Law and Regulations set standards and regulations for the management and protection of coastal resources. These standards are applicable to cap construction and slope protection activities which impact wetland and coastal areas. Remedial designs will be developed to minimize adverse impacts to these areas. If adverse impacts to wetland areas cannot be avoided as part of the selected remedy, appropriate mitigating actions will be taken.

4.2.4 Federal and State Hazardous Waste Regulations

The applicability of RCRA and Rhode Island Hazardous Waste Management Regulations depends on whether the wastes are RCRA-hazardous wastes as defined under these regulations. To date, there is no firm evidence available to indicate that RCRA-regulated materials were disposed of at the McAllister Point Landfill site. However, because toxic constituents are present in the waste materials and ground water, many portions of the federal and state hazardous waste regulations are relevant and appropriate to the selected remedy.

The substantive requirements of RCRA General Facility Standards, Preparedness and Prevention, and Contingency Plan and Emergency Procedures will be attained during remedial construction activities. RCRA Subpart F - Ground Water Protection stipulates ground water monitoring and corrective action requirements and establishes points of compliance. A ground water monitoring program will be implemented which will adhere to these requirements. Sections of Subpart G (Closure and Post-Closure Requirements) and Subpart N (Landfills) which define landfill closure requirements are relevant and appropriate to the capping and long-term monitoring of the site. RCRA Proposed Amendments for Landfill Closures and EPA Technical Guidance on Final Covers on Hazardous Waste Landfills and Surface Impoundments will be considered in the final design of the cap and development of the post-closure monitoring plan. Section 404 of the Clean Water Act will affect the design of the final cover, as discussed previously under the Location-Specific requirements.

Landfill cap construction and closure monitoring will be conducted in accordance with the applicable portions of Sections 7, 8, 9 and 10 of the Rhode Island Hazardous Waste Management Rules and Regulations and Proposed Amendments.

Portions of Section 5 of the Clean Air Act may be applicable or relevant and appropriate to the venting of landfill gas from the site. Monitoring and modeling would be required to determine if these requirements are applicable or relevant and appropriate. Venting of landfill gases will also be conducted in accordance with Regulations 1, 5, 7, 15, 17 and 22 of the Rhode Island Air Pollution Control Regulations.

Clean Water Act NPDES requirements and Rhode Island Water Quality Regulations for Water Pollution Control and RIPDES requirements will be applicable to the discharge of storm water from the site. A storm water monitoring program will be developed to meet these requirements during cap design activities.

5.0 PRE-DESIGN QUALITY ASSURANCE/QUALITY CONTROL PLAN

5.1 INTRODUCTION

This Quality Assurance Project Plan (QAPP) has been developed for use in conjunction with pre-design field sampling activities at the McAllister Point Landfill site in Middletown, Rhode Island. Navy policy calls for following EPA guidance and procedures while conducting investigations and remedial action at all Navy waste sites. The pre-design sampling program is designed to meet all applicable guidance for Superfund, RCRA, and the Navy IR program.

The QAPP serves as a controlling mechanism during field sampling, sample laboratory analysis, and data validation to ensure all data collected are valid, reliable, and legally-defensible. The QAPP outlines the organization, objectives, and Quality Assurance/Quality Control (QA/QC) activities which will ensure achievement of desired data quality goals.

5.2 PROJECT SCOPE

The objective of the pre-design field sampling activities are to gather sufficient information on the nature of site geotechnical and landfill gas conditions to allow adequate consideration of these issues during the design of a cap for the site.

The field activities and the associated sample matrices and analyses are discussed in Section 2.0 of this Work Plan. The sample program makes extensive use of Target Compound List (TCL) and Target Analyte List (TAL) analyses using EPA-CLP protocols, as defined in the USEPA Contract Laboratory Program (CLP) Statement of Work (SOW) for Organic Analysis; Multi-Media, Multi-Concentration; SOW No. 3/90; revised July 1991, and in the USEPA CLP SOW for Inorganic Analysis; Multi-Media, Multi-Concentration; SOW No. 3/90; revised September 1991. These EPA CLP requirements will be followed during this study. Naval Energy and Environmental Support Activity (NEESA) guidance (Sampling and Chemical Analysis Quality Assurance Requirements for the Navy Installation Restoration Program, NEESA 20.2-047B, 1988) for Level D analyses will also be followed by the laboratory. Where EPA-CLP protocols and NEESA guidance differ, the more stringent requirements will be followed.

5.3 PROJECT ORGANIZATION AND RESPONSIBILITIES

This project will be largely performed by TRC Environmental Corporation personnel. Project review will be performed by a Technical Review Committee assembled by the Northern Division. The names and addresses of select individuals involved in the project review and oversight appear below.

U.S. Navy - NORTHDIV

- Northern Division Code 1823
  Naval Facilities Engineering Command
  10 Industrial Highway, Mail Stop #82
  Lester, PA 19113

  Mr. James Briggs, Design Manager
  (215) 595-0590
  Mr. Francisco LaGreca, Engineer-In-Charge
  (215) 595-0567

- Naval Education and Training Center
  Public Works Dept., Bldg. 1
  Newport, RI 02841

  Lt. Jeffrey Borowy
  Mr. Brad Wheeler
  (401) 841-3735

TRC Environmental Corporation

- 5 Waterside Crossing
  Windsor, CT 06095

  Mr. Robert C. Smith, P.E., Program Manager
  Mr. Carl Stopper, P.E., Design Project Manager
  (203) 289-8631

U.S. Environmental Protection Agency

- Region I
  Federal Facilities Section
  90 Canal Street, 2nd Floor
  Boston, MA 02203

  Mr. Andrew Miniuks, Remedial Project Manager
  (617) 573-9614

Rhode Island Department of Environmental Management

- Air and Hazardous Materials Division
  291 Promenade Street
  Providence, RI 02908

  Mr. Paul Kulpa
  (401) 277-2797

The responsibilities of TRC's Project Manager and QA/QC staff are briefly described below.

<u>Project Manager's Responsibility</u>

The TRC Project Manager will provide overall direction to the project team, and will be held responsible for successful project completion. The Project Manager will be the primary contact for the Northern Division's Engineer-In-Charge (EIC).

<u>QA Manager's Responsibility</u>

TRC's Corporate QA Manager will be the responsible Quality Assurance Officer for this project. The QA Manager reports independently to the Corporate President and, hence, has full authority to act independently from the technical line management structure. He will serve as TRC's primary contact with the Northern Division's QA staff, if so requested by the EIC. He will monitor compliance of the project with the project plan, and perform any necessary performance or system audits. The TRC QA Manager will initiate and monitor any necessary formal corrective actions.

<u>Field QC Coordinator's Responsibilities</u>

A Field QC Coordinator will be selected for this project. The Field QC Coordinator will work with the field team in preparing for the sampling events, and also during the field work. He or she will be on site to ensure required QC procedures are followed for sample collection and handling; will initiate informal and/or formal corrective actions, as necessary; and will maintain and report QC records and results to the TRC Project Manager and QA Manager. The

QC field coordinator will also serve as the QA/QC Manager for the project. This person will be responsible for ensuring all analytical deliverables have been received in accordance with this QAPP.

Laboratory QC Coordinator

The analytical laboratory selected for this project, a NEESA-approved and EPA CLP laboratory, will also designate a QC Coordinator who will function as part of the project QC team. The duties of the laboratory QC Coordinator or designee will include, at a minimum, the following:

- Direct preparation of sample containers;
- Direct preparation and inclusion of blind QC samples in sample load in a fashion unrecognizable to analysts;
- Monitor use of known QC samples, blanks and duplicates, as required by specific projects;
- Maintain records of performance on known and blind QC samples as a measure of analytical precision and accuracy (control charts, etc.); and
- Direct and monitor recordkeeping and sample tracking activities.

5.4 QUALITY ASSURANCE OBJECTIVES FOR MEASUREMENT DATA

The overall quality assurance objective for laboratory analysis of environmental samples is to provide a laboratory QA/QC program that is, at a minimum, equal to the U.S. EPA Contract Laboratory Program (CLP). The quality control limits of accuracy and precision for laboratory analyses are governed by the methods and equipment used. Laboratory QA/QC requirements defined in CLP protocol are designed to ensure that acceptable levels of data accuracy and precision are maintained throughout the analytical program. These requirements are detailed in the U.S. EPA CLP Statement of Work (SOW) for Organic Analysis; Multi-Media, Multi-Concentration; SOW No. 3/90; revised August 1991 and in the U.S. EPA CLP SOW for Inorganic Analysis; Multi-Media, Multi-Concentration; SOW No. 3/90; March 1990. These requirements will be followed during this study.

It must be recognized that QA objectives may be attainable only for samples that are homogeneous and do not have inherent matrix-related problems. In the event that QA objectives cannot be met on specific samples, groups of samples or sample types, the analytical laboratory will make every reasonable effort to determine the cause of non-attainment and, if such is due to instrument malfunction, operator error, or other identifiable cause within the control of the laboratory, the samples affected will be reanalyzed, if possible. Should non-attainment of QA objectives be due to sample inhomogeneity, sample matrix interference, or other sample-related causes, reanalyses will be treated as additional analyses.

For many EPA-approved methods, interlaboratory method verification studies have been used to establish QC criteria which may be regarded as an inherent part of the method. In those cases, such criteria will take precedence except for deviations from such criteria that can be reasonably attributed to sample-related cases.

The quality assurance objectives for all measurement data include considerations of precision, accuracy, completeness, representativeness, and comparability as described below.

5.4.1 Precision and Accuracy

The precision of a measurement is an expression of mutual agreement of multiple measurement values of the same property conducted under prescribed similar conditions. Precision reflects the repeatability of the measurement. Precision is evaluated most directly by recording and comparing multiple measurements of the same parameter on the same sample under the same conditions. Precision is usually expressed in terms of the standard deviation. The precision objectives for analytical parameters are specified in the CLP protocols.

The degree of accuracy of a measurement is based on a comparison of the measured value with an accepted reference or true value, or is a measure of system bias. Accuracy of an analytical procedure is best determined based on analysis of a known or "spiked" sample quantity. The degree of accuracy and the recovery of analyte to be expected for the analysis of QA samples and spiked samples is dependent upon the matrix, method of analysis, and compound or element being determined. The concentration of the analyte relative to the detection limit is also a major factor in determining the accuracy of the measurement. Except as otherwise specified by a method, the QC objective for accuracy under this project will be 75 to 125 percent (percent recovery), as determined by sample spike recoveries. Alternately, accuracy may be assessed through the analyses of appropriate standard reference materials, certified standards, or samples, as available.

5.4.2 Completeness

Completeness is a measure of the amount of valid data obtained from the measurement system relative to the amount anticipated under ideal conditions. This project's QC objective for completeness, as determined by the percentage of valid data generated, will be $\geq$90 percent.

5.4.3 Representativeness

Samples taken must be representative of the population. Where appropriate, the population will be statistically characterized to express: 1) the degree to which the data accurately and precisely represent a characteristic of a population, 2) parameter variations at a sampling point, and 3) a process, or an environmental condition. Sample selection and handling procedures will be conducted to obtain the most representative sample possible. Sampling devices will be decontaminated between sampling points to ensure that cross-contamination does not occur between samples.

Representative samples will be collected through the following actions:

- Collect samples from locations fully representing the site conditions;
- Use appropriate sampling procedures and equipment;
- Use appropriate analytical methodologies; and
- Analyze for appropriate parameters using appropriate detection limits.

Field duplicate and blank samples, as well as trip blank samples will not be collected or prepared, as part of this project. Sampling locations and procedures are intended to assure collection of representative samples.

The laboratory will make appropriate efforts to assure that the samples are adequately homogenized prior to taking aliquots for analysis, so reported results represent samples received.

5.4.4 Comparability

Consistency in sample acquisition, handling, analysis and level of QA/QC is necessary so that the analytical results may be compared. Where appropriate, the results of the analyses will be compared with the results obtained in previous studies. The laboratory will also use EPA-approved methods and reporting units, in order to assure that the data will be comparable to other similarly generated data sets.

5.5 SAMPLING PROCEDURES

The following matrices will be sampled during the field investigation portion of the design of the McAllister Point Landfill cap: soil, sediment, and landfill gas. Sample collection and monitoring methodology are presented in Appendix A of this Work Plan. These procedures will be implemented in order to collect representative data for pre-design planning guidance.

5.5.1 Sample Collection, Handling, and Shipping

It is important to use appropriate sample containers so that no chemical alteration occurs between the collection of samples in the field, and the receipt of samples at the laboratory. The sample bottles will be prepared and shipped to the field by the laboratory, under the direction of the laboratory QC coordinator. The sample bottles will be transported to the site within a sealed shipping cooler.

Sample containers will be selected to ensure compatibility with the potential contaminants and to minimize breakage during transportation. Sample containers, analytical methods and preservation required are listed in Table 5 for soil, sediment, and landfill gas samples. Holding times are further defined in Table 6.

Sample labels will be filled out at the time of sampling and will be affixed to each container to identify the sample number, collector's name, date and time of collection, location of the sampling point, preservatives added, and analyses requested for the sample.

After the bottles for a given sample site have been filled, they will be placed in a shipping cooler. Field personnel will add bags of crushed ice or ice packs to the shipping coolers as the samples are collected. Each sample container will be cushioned with packing materials and sealed in a refrigerated cooler container for shipment to the laboratory by overnight delivery. Daily sample collection activities will be scheduled in order to assure overnight delivery of samples.

A chain-of-custody record will be prepared and will accompany all samples to provide documentation of all samples collected and to trace sample possession. Chain-of-custody procedures are discussed in detail in Section 5.6.

5.5.2 Field Equipment Decontamination Procedures

Drilling equipment will be decontaminated prior to use at the McAllister Point Landfill. Decontamination of drill rigs and drilling equipment (e.g., augers, rods) will be conducted upon completion of all field work at designated decontamination areas with a steam cleaner. Decontamination of sampling equipment will be performed at designated decontamination areas. Sampling equipment such as hand augers, stainless steel spoons or spatulas, and stainless steel mixing bowls will be decontaminated using the following procedures:

- Wash and scrub with low phosphate detergent in tap water;
- Rinse with tap water;
- Rinse with 10% nitric acid (1% nitric acid on carbon steel split-spoons);
- Rinse with tap water;
- Rinse with hexane and methanol - pesticide grade solvents or better;
- Rinse with distilled water (demonstrated to be analyte-free);
- Air dry - on clean polyethylene sheeting; and
- Wrap in aluminum foil, shiny side out for transport (if not being used immediately).

NOTE: Clean equipment may rest on -- but never be wrapped in clean polyethylene sheeting.

An attempt will be made to coordinate a drilling sequence hierarchy from less likely to more likely contaminated boring locations to reduce the potential for cross-contamination between locations. Sampling equipment will be decontaminated prior to use at each sampling location.

Decontamination rinsates will be collected and contained in drums for subsequent determination of proper handling and/or disposal as outlined in the Investigation Derived Waste Plan provided as Appendix B.

5.6 SAMPLE CUSTODY

Sample custody procedures will be observed to ensure the validity of the data generated during this program. Sample chain-of-custody will be initiated with selection and preparation of the sample containers. To reduce the chance for error, the number of personnel handling samples will be restricted, and one person will be assigned the responsibility of field sample custodian.

On-site monitoring data will be controlled and entered daily in permanent log books, as appropriate.. Personnel involved with the sample chain-of-custody process will be trained in sample collection and handling procedures prior to project initiation.

Sample custody and documentation procedures described in this section will be followed throughout all sample collection activities at NETC-Newport. Components of sample custody procedures include the use of field notebooks, sample labels, and chain-of-custody forms.

5.6.1 Field Notebooks

The TRC project manager will oversee the maintenance of field notebooks. Field notebooks will be bound books, preferably with consecutively numbered pages, that are at least 4 inches x 7 inches in size. Field notebooks will be maintained by the TRC field team leader and other team members to provide a daily record of significant events, observations, and measurements during the field investigation activities. Notebook entries will be signed and dated.

Information pertinent to the field survey and/or sampling will be recorded in the notebooks. Field notebook entries will include the following information (at a minimum):

- Name and affiliation of field contact;
- Name and title of author, date and time of entry, and physical/ environmental conditions during field activity;
- Names of field crew;
- Names and titles of any site visitors;
- Type of sampling activity;
- Location of sampling activity;
- Description of sampling point(s);

Date and time of sample collection;
Sample media (e.g., soil, sediment, ground water, etc.);
Sample collection method;
Number and volume of sample(s) taken;

- Analyses to be performed;
- Sample preservatives;
- Sample identification number(s);
- Field observations;
- Any field measurements made such as Ph, temperature, conductivity, water level, etc.;
- References for all maps and photographs of the sampling site(s); and

Original data recorded in either the field notebooks, on sample labels, or in the chain-of-custody records will be written with waterproof ink. None of these accountable, serialized documents will be destroyed or discarded, even if they are illegible or contain inaccuracies.

If an error is made on an accountable document assigned to an individual, that individual will make all corrections by crossing a line through the error and entering the correct information and initialing the cross-out. The erroneous information will not be obliterated. Any subsequent error discovered on an accountable document will be corrected by the person who made the entry, and will be initialed and dated, as appropriate.

5.6.2 Sample Labels

Samples obtained at the site will be placed in an appropriate sample container for preservation prior to shipment to the laboratory. Each sample will be individually identified with a separate identification label recorded with a unique sample identifier. The information recorded on the label will include:

- Project name/project number/location;
- Sample identifier/number;
- Analysis to be performed;
- Preservatives used, especially any non-standard types, and any other field preparation of the sample;
- Date of collection;
- Number of containers per analyte (i.e., 1 of 2, etc.); and
- Sampler's initials.

5.6.3 Custody Seals

Samples will be placed in sample coolers and the coolers will be sealed with custody seals prior to shipment to the laboratory. Clear adhesive tape will be placed over the seals to ensure that seals are not accidentally broken during shipment.

5.6.4 Chain-of-Custody Records

All samples will be accompanied by a chain-of-custody record, an example of which is shown on Figure 9. A chain-of-custody record will accompany the sample from initial sample container selection and preparation commencing at the laboratory, to the field for sample containment and preservation, and through its return to the laboratory. If samples are split and sent to different laboratories, a copy of the chain-of-custody record will be sent with each sample.

The "Remarks" column in the chain-of-custody record will be used to record specific considerations associated with sample acquisition such as: sample type, container type, and sample preservation methods. When transferring samples, the individuals relinquishing and assuming sample custody will sign, date, and note the transfer time on the record.

A minimum of two copies of the chain-of-custody record will follow each sample to the laboratory. The laboratory will maintain one file copy, and the completed original will be returned to the TRC Project Manager. A copy of the completed original will be returned as a part of the final analytical report. This record will be used to document sample custody transfer from the sampler, to another TRC team member, to a shipper, or to the laboratory, and also to verify the date of sample receipt in the laboratory.

Shipments will be sent by overnight carrier with appropriate bill of lading documentation. Bills of lading will be retained as part of the permanent program documentation.

5.6.5 Sample Shipment

Samples will be delivered to the laboratory for analysis as soon as practical after the number of samples and sample containers is sufficient to comprise a shipment, preferably the same day the samples are collected. Sample shipment will occur at a minimum frequency of every other day. All samples will be stored in coolers at a temperature of 4°C unless otherwise specified by the method. The samples will be accompanied by the chain-of-custody record. During sampling and sample shipment activities, the TRC field team leader (or his designee) will contact the laboratory daily to provide information about impending shipments.

5.6.6 Sample Master Log Notebook

In addition to the field notebook documentation, each sample will be documented in a master sample log notebook for future reference. This master sample log will include the following information: sample identifier, sampling date and time (military), sampling personnel, matrix type (i.e., soil), containers/parameters for analysis, date and method of shipment, any sample preservation, and any other pertinent information relating to the sample(s). The master sample log will be consistently updated during sampling activities in the field for review during field audits. Upon completion of sampling activities, the master sample log notebook will be delivered to the TRC Project Manager.

5.6.7 Laboratory Sample Custody

The TRC Field QC Coordinator will notify the laboratory of upcoming field sampling activities and subsequent sample transfer to the laboratory. This notification will include information concerning the number and type of samples to be shipped, as well as the anticipated sample arrival date.

The laboratory will designate a sample custodian who will be responsible for maintaining sample custody and for maintaining all associated custodial documentation records. After receiving the samples, the sample custodian will check the original chain-of-custody record and request for analysis documents against the labeled contents of each sample container for correctness and traceability. The sample custodian will then sign the chain-of-custody record and record the date and time that the sample shipment was received at the laboratory. The samples will then be logged into the laboratory system.

Care will be exercised in the laboratory to annotate any labeling or descriptive errors associated with the sample containers. In the event of discrepant documentation, the laboratory will immediately contact the TRC Field QC Coordinator as part of the corrective action process. A qualitative assessment of each sample container will be performed to note any anomalies, such as broken or leaking bottles. This assessment will be recorded as part of the incoming chain-of-custody procedure.

Samples will be stored in a secured dark area and at a temperature of approximately 4°C, if necessary, until analyses are performed. A laboratory chain-of-custody record will accompany the sample or sample fraction through final analysis for sample control. A copy of the chain-of-custody record will accompany the laboratory's analytical report and will become a permanent part of the project's records. The Ph of incoming water samples will be checked by the laboratory when preservatives have been added to the sample. Details of the chain-of-custody for laboratory activities will be provided in the laboratory's QA manual.

5.6.8 Evidence File

The TRC Project Manager will serve as file custodian. At the project's completion, the files will be returned to the Navy's Northern Division Office where they will be permanently archived.

The evidence file will contain all incoming materials related to the project such as: sketches, correspondence, authorizations, and logs. These documents will be placed in the project file as soon as possible. If correspondence is needed for reference by project personnel, a copy will be made rather than manipulating the original.

Examples of the types of records that will be maintained in the project file are:

- Field documents;
- Correspondence;
- Photographs;
- Laboratory data;
- Reports; and
- Subcontract agreements.

To prevent the inadvertent use of obsolete or superseded project-related procedures, all personnel of the laboratory and project staffs will be responsible for reporting changes in protocol to the Laboratory Project Manager and the Laboratory Director. The Laboratory Project Manager and Laboratory Director will then inform the project and laboratory staffs and the Quality Assurance Officer of these changes, as appropriate.

Revisions to procedures shall be subject to the same level of review and approval as the original document. Outdated procedures shall be marked "void". The voided document may be destroyed at the request of the Laboratory Project Manager; however, it is recommended that one copy of the voided document be maintained in the project file. The date and reason why the document was voided will be recorded.

5.7 CALIBRATION PROCEDURES AND FREQUENCY

Instruments and equipment used to gather, generate, or measure environmental data will be calibrated with sufficient frequency and in such a manner that accuracy and reproducibility of results are consistent with the instrument manufacturer's specifications.

Laboratory instrumentation calibration procedures and frequencies are specified in the most recent Contract Laboratory Program (CLP) Statement of Work (SOW) for Organic Analysis; and will be strictly followed for those analytes analyzed by CLP protocols. For all other analyses for which EPA-approved methods exist, the laboratory will employ such methods and follow the specified calibration procedures and frequencies. The laboratory quality control program includes strict adherence to routine calibration procedures.

Analysis of blank samples, duplicate samples, spiked blanks, and matrix blanks will be performed where possible to document the effectiveness of calibration procedures. Method blanks contain all the reagents used in the preparation and analysis of the samples and are processed through the entire analytical scheme to assess spurious contamination from reagents, glassware and other materials used during analysis. The terms method blank and laboratory blank are interchangeable. A matrix blank denotes a blank of a similar matrix (e.g., for liquids a blank of distilled-deionized reagent grade high purity water may be used; for soils/sediments high purity sand may be used). A spike blank is a method blank which has had a known concentration of a particular compound or analyte added to it to assure adequate percent recovery of the compound/analyte.

Records of calibration, repair, or replacement will be maintained by the designated laboratory personnel performing quality control activities. Calibration records of assigned laboratories will be filed and maintained at the laboratory location where the work is performed and subject to QA audit.

Calibration of field instruments will be performed at approved intervals as specified by the manufacturer or more frequently, as conditions dictate. At a minimum all field instruments will be calibrated at the beginning and end of each day. Calibrations may also be performed at the start and completion of each test run; however, such calibrations will be re-initiated as a result of delay due to meals, work shift change, or instrument damage. Calibration standards used as reference standards will be traceable to the National Bureau of Standards (NBS), when possible. Calibration procedures for field instruments will be as specified by the instrument manufacturer. Equipment manuals describing calibration procedures will be maintained in the field office during site investigations.

5.8 ANALYTICAL PROCEDURES

EPA-approved methods will be used for all analyses for which such methods exist. Target Compound List (TCL) and Target Analyte List (TAL) parameters will be analyzed by Contract Laboratory Program (CLP) protocols. The laboratory will follow methods detailed in the CLP Statement of Work (SOW) for Organic Analyses, Multi-media, Multi-concentration, 3/90, revised July 1991, and the SOW for Inorganics Analyses, Multi-media, Multi-concentration, 3/90, revised September, 1991.

If sample contaminant concentrations are high, then CLP protocols for low and medium concentration samples may be required. In this case, sample runs at lower dilutions will be performed to obtain quantitative results for parameters present at lower concentrations. That is, samples are pre-screened to estimate concentration levels. According to EPA methodology, high concentration samples are diluted to bring them within a linear working range. Low concentration samples are set aside and then analyzed within the same linear working range. It may not be possible to quantitate sample results in parts per billion for samples where "pure" waste (fuel product, paint, powder, etc.) is encountered. A decision tree approach will be followed, in order to quantitate the sample when high levels of contamination are encountered. In this case, detection limits will be raised for all analytes on the sample, as the sample is diluted.

5.8.1 Target Compound List - Organic Compounds

Organic compound analyses will be conducted according to the U.S. EPA CLP, Statement of Work for Organic Analyses, SOW 3/90, revised August 1991. The organic compounds contained in the TCL will be determined using proven methods to identify and quantify volatile, semi-volatile and pesticide/PCB compounds. The TCL compounds and CLP-required detection limits are shown in Tables 7 through 9. The actual detection limits obtainable for a specific sample depend upon matrix interferences. If the CLP detection limit is unachievable for a particular sample, an explanation of the problem and supporting evidence will be provided by the laboratory in the case narrative summary submitted with the deliverables.

Each set of samples will be analyzed in conjunction with the analysis of QC samples, including blanks, matrix spikes and matrix spike duplicate (MS/MSD) samples for quality control determinations. The frequency of analysis of the QC samples will not be less than one per 20 samples for MS/MSD samples. All samples, laboratory duplicates, laboratory blanks, matrix spike and matrix spike duplicates will be fortified with surrogate spiking compounds as shown in Table 10.

5.8.2 Target Analyte List - Metals

Water and soil samples will be prepared for analyses as described by procedures for each respective matrix and analysis method described in the U.S. EPA CLP, Statement of Work for Inorganic Analyses (SOW 3/90). Each set of samples, or 20 samples, whichever is more frequent, will be analyzed with a preparation blank, duplicate sample, and matrix spiked sample. Each group of 20 samples will be analyzed with a laboratory control sample of similar matrix. The Target Analyte List (TAL) for metals and inorganics and associated detection limits are listed in Table 11.

The atomic absorption (AA) instrument will be calibrated through the use of a minimum of three calibration standards prepared by dilution of certified stock solutions. Calibration standards will contain acid(s) at the same concentration as the digestates. An analysis blank will then be prepared, and one calibration standard will be at the EPA-CLP required detection limit for the metal being evaluated. The other standard concentrations will bracket the concentration range of the samples. A continuing calibration standard, prepared from a different stock solution than that used for the calibration standards, will be prepared and analyzed after every ten samples or every two hours of continuous instrument operation. The value of the continuing calibration standard concentration must agree with requirements of the CLP SOW.

5.8.3 Landfill Gas Parameters

Landfill gas samples will be analyzed for VOCs using as gas chromatograph/mass spectrophotometer technique which is a modification of EPA Methods T01 and T02. VOCs detected by the GC/MS analytical method are provided in Table 12.

5.9 DATA REDUCTION, VALIDATION, AND REPORTING

The procedures used for calculations and data reduction are specified in each analytical method referenced in Section 5.8. Raw data will be entered in bound laboratory notebooks. A separate book will be maintained for each analytical procedure. The data will be entered such that sufficient space remains to enter all subsequent calculations required to arrive at the final (reported) value for each sample. Calculations include factors such as sample dilution ratios, corrections for titrant normality, and conversion to dry-weight basis for solid samples. Instrument chart recordings and calculator printouts will be labeled and attached to their respective pages, except for voluminous gas chromatograms which will be cross-referenced and stored separately.

Calculations will be checked from the raw data to final value stages prior to reporting the results for a group of samples. Results obtained from extreme ends of standard curves generated by linear regression calculator programs will be checked against graphically-produced standard curves if the correlation coefficient of a program curve is less than 0.995.

Data will generally be reported as micrograms of analyte per liter for aqueous samples or micrograms per kilogram (dry weight) for solid or non-aqueous liquid samples. Concentration units will always be listed on reports and any special conditions, such as dry weight conversions, will be noted. The data reporting form will also include the unique sample number assigned to each sample, details of sample collection including the client's identification number, and the dates of sample receipt and report preparation.

5.9.1 Data Reduction

Target Compound List Compounds

Instrument performance test data will accompany the raw data during data reduction. The following criteria must be attained to make a qualitative identification of an organic pollutant using Gas Chromatograph/Mass Spectrometer (GC/MS) techniques:

Characteristic ions for each compound of interest must maximize in the same or within one scan of each other.

Retention time must occur within ± 1 percent of the retention time of the authentic compound.

Relative peak heights of the three characteristic ions in the Extracted Ion Current Profile (EICP) must fall within $\pm$ 20 percent of the relative intensities of these ions in a reference mass spectrum. The reference mass spectrum can be obtained by a standard analyzed in the GC/MS system or from a reference library.

- The entire mass spectrum of the compound of interest is compared to the reference compound.

Structural isomers having similar mass spectra can be explicitly identified only if the resolution between authentic isomers in a standard mix is acceptable. Acceptable resolution is achieved if the baseline-to-valley height between the isomers is less than 25 percent of the sum of the two peak heights. Otherwise, structural isomers are identified as isomeric pairs.

When a compound has been identified, the quantitation of that compound is based on the integrated abundance from the EICP of the primary characteristic ion. The base peak ion of internal and surrogate standards is used in the quantitation. If the sample produces an interference for the first listed ion, a secondary ion is used to quantitate. Quantification is performed using internal standard techniques.

To ensure that reported data are accurate, all resultant data are verified. Retention items and area counts are checked carefully for correct identification and accurate quantification.

Metals

The concentrations of metals determined by Atomic Absorption Spectroscopy (AAS) measurements are obtained by comparison of absorbance values with those obtained from the analyses of known standards. A linear regression plot of absorbance versus concentration will be used to determine a concentration factor for linearity of response.

In the event of low (<85%) or high (>115%) post-digestion spike recovery, the analysis will be repeated using the method of known additions to determine potential matrix interferences. CLP criteria will be maintained for analyses of samples of similar matrix. The mean percentage recovery and standard deviation will be calculated from a minimum of 20 analyses. A warning limit of ± 2 standard deviations from the mean and a control limit of ± 3 standard deviations will be used to establish that the test is providing accurate data.

5.9.2 Data Validation

Data validation is the process of reviewing data and associated quality control criteria and accepting, qualifying, or rejecting it on the basis of sound criteria. Project supervisory and QC personnel will use validation methods and criteria appropriate to the type of data and the purpose of the measurement. Records of all data will be maintained, even that judged to be an "outlying" or anomalous value. The QA/QC Manager validating the data will have sufficient knowledge of the technical work to identify questionable values.

Field Data Validation

Field sampling data will be validated by the TRC Field QC Coordinator or QA/QC Manager, based on their judgment of the representativeness of the sample, maintenance and cleanliness of sampling equipment, and adherence to the approved, written sample collection procedure.

The following criteria will be used to evaluate the field sampling data:

- Use of approved sampling procedures;
- Use of reagents/standards that conform to QC-specified criteria; and
- Proper chain-of-custody maintained and documented.

5.10 INTERNAL QUALITY CONTROL CHECKS AND FREQUENCY

Quality control checks will be performed to ensure the collection of representative samples and the generation of valid analytical results on these samples. These checks will be performed by project participants through the program under the guidance of the TRC QA Officer.

5.10.1 Data Collection and Sampling QC Procedures

The TRC internal QC checks for the sampling aspects of this program will include, but not be limited to, the following:

- Use of field notebooks to ensure completeness, traceability, and comparability of the samples collected.

  Field checking of field notebooks and sample labels by a second person to ensure accuracy and completeness.

- Strict adherence to sample chain-of-custody procedures.

- Calibration of the field monitoring equipment (e.g., HNU, OVA).

5.10.2 Analytical QC Procedures

Quality control checks will be performed to ensure the collection of representative samples and the generation of valid analytical results on these samples. These checks are performed by project participants under the guidance of QC personnel.

The laboratory will make use of various types of QC samples to document the validity of the generated data. The following types of QC samples are routinely used:

> Calibration Check Samples--One of the working calibration standards which is periodically used to check that the original calibration is still valid.
>
> Spiked Samples--Replicate aliquots of project samples are spiked with components of interest and carried through the entire preparative and analytical scheme.
>
> Laboratory Control Samples (LCS)--These samples are prepared from EPA Environmental Monitoring Systems Laboratory (EMSL) concentrates or National Bureau of Standards (NBS) standard reference materials. The LCS are used to establish that an instrument or procedure is in control. An LCS is normally carried through the entire sample preparation and analysis procedure.

Surrogate Spikes--Samples requiring analysis by GC/MS are routinely surrogate-spiked with a series of deuterated analogues of the components of interest. It is anticipated that these compounds would assess the behavior of actual components in individual program samples during the entire preparation and analysis scheme.

Matrix Spikes/Matrix Spike Duplicates (MS/MSD)--One MS/MSD pair will be run per 20 samples for each different matrix analyzed. These pairs will be spiked with the target compounds of concern for that matrix.

All values which fall outside the QC limits described in the analytical method will be noted. The following analytical guidelines will be used to check recovery values which fall outside the QC limits:

1. All recovery data are evaluated to determine if the QC limits are appropriate and if a problem may exist even though the limits are being achieved (e.g., one compound that is consistently barely within the lower limit).

2. All recovery data which are outside the established limits are evaluated. This evaluation includes an independent check of the calculation.

3. Corrective action is performed if any of the following are observed:

   - All recovery values in any one analysis are outside the established limits.
   - Over 50 percent of the values for a given sample set are outside limits.
   - One compound is outside the limits in over 50 percent of the samples.

Reagents used in the laboratory are normally of analytical reagent grade or higher purity. Each lot of acid or solvent used is checked for acceptability prior to laboratory use. All reagents are labeled with the date received and date opened. All glassware is precleaned according to specifications contained in the analytical method. Standard laboratory practices for laboratory cleanliness, personnel training, and other general procedures are used.

Laboratory Control Charts

The control chart displays data in a format which graphically compares the variability of all test results with the average or expected variability of small groups of data. The variability may be due to random (indeterminate) or assignable (determinate) causes. The control chart distinguishes indeterminate from determinate variation in a process or method by its control limits. If a value falls outside the control limits, it is considered out-of-control, almost certainly due to a determinate cause which has been added to the indeterminate variations. The control chart signals the need to investigate, find the determinate cause, and correct it. Construction of a control chart requires a minimum of 14 to 20 duplicate sets of data points (which limits its use).

QC samples and instrument calibrations lend themselves most readily to the gathering of the data. Calculation of control limits and the values are usually plotted chronologically so that trends or cycles can be readily detected. If QC sample measurements show an out-of-control condition, it can be expected that subsequent sample analyses might yield invalid data. The control chart is an effective indicator of the need for corrective action.

For volatile and semi-volatile organics and pesticide analyses performed by GC/MS, surrogate recoveries from the method blank are the control sample. For other organics (e.g., PCBs, dioxins/furans), an LCS (spiked blank) is used to plot the control charts. An LCS is also used as the control point for inorganic analyses.

5.11 SPECIFIC ROUTINE PROCEDURES USED TO ASSESS DATA PRECISION, ACCURACY, AND COMPLETENESS

Procedures used to assess data precision and accuracy will be in accordance with 44 FR 69533 "Guidelines Establishing Test Procedures for the Analyses of Pollutants", Appendix III Example Quality Assurance and Quality Control Procedures for Organic Priority Pollutants", December 3, 1979. Completeness is recorded by comparing the number of parameters initially analyzed with the number of parameters successfully completed and validated. For this project, a target control limit of greater than 90 percent will be used.

Accuracy

The percent recovery is calculated as:

$$\% = \frac{S_o - S_s}{S} \times 100$$

where:

S_o = The background value, i.e., the value obtained by analyzing the sample.
S = Concentration of the spike added to the sample.
S_s = Value obtained by analyzing the sample with the spike added.
$\%$ = Percent recovery.

Precision

The relative percent difference is calculated as:

$$1/2 \text{ x } \frac{(V_1 - V_2)}{(V_1 + V_2)} \text{ x } 100 = \% \text{ difference}$$

where: V_1, V_2 = The two values obtained by analyzing the duplicate samples.

Completeness

Completeness will be reported as the percentage of all measurements made whose results are judged to be valid. The following formula will be used to estimate completeness:

$$C = 100 \text{ X } \frac{V}{T}$$

where: C = Percent completeness.
V = Number of measurements judged valid.
T = Total number of measurements.

5.12 CORRECTIVE ACTION

The acceptance limits for the sampling and analyses under this program will be those stated in the method or defined by other means in the QAPP. Corrective actions are often immediate in nature, implemented by the analyst or Project Manager. The corrective action usually involves recalculation, reanalysis, or repeating sample collection.

5.12.1 Immediate Corrective Action

If an immediate corrective action can be taken as part of normal operating procedures, the collection of poor quality data can be avoided. Instrument and equipment malfunctions are amenable to this type of action. QC procedures include troubleshooting guides and corrective action suggestions. The actions taken will be noted in field or laboratory notebooks, but no other formal documentation is required, unless further corrective action is necessary. These on-the-spot corrective actions are an everyday part of the QA/QC system.

Corrective action during the field sampling portion of a program is most often a result of equipment failure or an operator oversight and may require repeating a sampling run. Operator oversight is best avoided by having field crew members audit each others' work before and after a test. Every effort will be made by the field team leader to ensure that all QC procedures are followed. If potential problems are not solved as an immediate corrective action, TRC will apply formalized long-term corrective action, if necessary.

Corrective action for analytical work will include recalibration of instruments, reanalysis of known QC samples and, if necessary, reanalysis of actual field samples. Specific QC procedures and checklists are used by the laboratory to help analysts detect the need for corrective action. Often the person's experience will be valuable in alerting the operator to suspicious data or malfunctioning equipment.

5.12.2 Long-Term Corrective Action

The need for long-term corrective action may be identified by standard QC procedures, control charts, performance or system audits. Any quality problem which cannot be solved by immediate corrective action falls into the long-term category. The TRC QA system ensures that the quality problem is reported to a person responsible for correcting it, and who is part of a closed-loop action and follow-up plan.

The essential steps in the closed-loop corrective action system are listed below:

- Identify and define the problem;
- Assign responsibility for investigating the problem;
- Investigate and determine the cause of the problem;
- Determine a corrective action to eliminate the problem;
- Assign and accept responsibility for implementing the corrective action;
- Establish effectiveness of the corrective action and implement it; and
- Verify that the corrective action has eliminated the problem.

Documentation of the problem is important to the system. A Corrective Action Request Form is filled out by the person finding the quality problem. This form identifies the problem, possible causes, and the person responsible for action on the problem. The responsible person may be an analyst, field team leader, QC coordinator, or the QA Officer. If no person is identified as responsible for action, the QA Officer investigates the situation and determines who is responsible in each case.

The Corrective Action Request Form includes a description of the corrective action planned and the date it was taken, and space for follow-up. The QA Officer checks to be sure that initial action has been taken and appears effective and, at an appropriate later date, checks again to see if the problem has been fully solved. The QA Officer receives a copy of all Corrective Action Forms and enters them in the Corrective Action Log. This permanent record aids the QA Officer in follow-up and makes any quality problems visible to management. The log may also prove valuable in listing a similar problem and its solution.

5.12.3 Out-of-Control Events and Corrective Action

Procedures are outlined as to what corrective action is taken if an out-of-control event occurs, and how it is documented and used to improve laboratory performance. Procedures for assuring that results for samples processed during out-of-control conditions are not reported are also outlined, as well as the conditions necessary to reestablish control and criteria for assuring the system is operating properly. The documentation is easily used by all personnel and is part of routine laboratory procedure.

It is recognized that several levels of out-of-control events may occur. Three examples are given below with corrective actions to be taken:

1. Observations Corrected by Analyst at the Bench--The calibration of an instrument is not linear. The analyst finds this and corrects it prior to continuing to analyze samples. The laboratory documents this event and notes that the corrective action was to recalibrate, and that no samples were affected as none were analyzed prior to calibration.

2. Corrective Actions Taken by Supervisor--A matrix spike recovery is out-of-control and the laboratory supervisor finds this after the samples for the day have been analyzed. The supervisor documents that the laboratory blank spiked with surrogates or standards was in control and that other sample spikes were in control, therefore, no re-analysis of the sample is required.

3. Corrective Actions at the Receiving Level--The sample container is broken. The analyst notes this and documents whether or not more sample is available. If no more sample is available, TRC is notified and the decision documented.

6.0 INITIAL DRAFT CONSTRUCTION QA/QC PROJECT PLAN

6.1 INTRODUCTION

A Quality Assurance/Quality Control (QA/QC) plan is developed to ensure that the remedial system is constructed as specified in the design (quality assurance) and to allow implementation of a system of inspections and tests to monitor and control the quality of the construction project (quality control). The Construction Quality Assurance Plan guidance is incorporated into the construction specifications as part of the Navy's standard construction documents and is implemented during remedial construction through the use of an Independent Quality Assurance Team. The Construction Quality Control Plan is prepared by the remedial action constructor and defines activities necessary to manage, control and document work so as to ensure compliance with project requirements (i.e., plans and specifications).

6.2 INDEPENDENT QUALITY ASSURANCE TEAM

An Independent Quality Assurance Team will be established using the in-place Navy system for management of construction projects for the capping of the McAllister Point Landfill. The QA team will consist of separate consultants or "in-house" (e.g., Navy) personnel assigned to the project. These personnel will be responsible for examining and testing various materials, procedures, and equipment during construction activities. The qualifications and expertise of the team members will be commensurate with the scope of the project. Members of the QA Team will be independent of the constructor of the remedial action so that the results of the quality assurance effort are unbiased and objective. At this stage in the remedial design effort, identification of potential team members is premature. The final Construction QA/QC Project Plan will define the responsibilities and authorities of the organizations and key personnel involved in the design and construction of the remediation system.

6.3 QUALITY ASSURANCE PLAN

The QA plan specification will require the contractor to detail the project QA requirements. The plan will identify and define quality control measures to plan, check, and review all work before it is delivered to the client or used for construction purposes. The plan will establish the organization of the project and assign responsibility for various quality assurance issues to the construction contractor, design engineer, "in-house" personnel and appropriate regulatory agencies, as appropriate, for implementation during the remedial action construction activities. Typical activities which will be monitored under the QA program include the following:

- Review of shop drawings, product data and samples;
- Inspection of materials prior to installation to verify compliance with specifications;
- Construction monitoring;
- Monitoring of installation, testing and sampling methods to verify acceptance of materials used in construction;
- Establishment of a set of "record documents", when required, based upon information supplied by the contractor or vendor.

6.4 CONSTRUCTION QUALITY CONTROL ACTIVITIES

Construction quality control activities will be defined within the 35% complete remedial action specifications package. These specifications will require submittal of a Quality Control plan by the remedial contractor and will require that the plan include the following:

- Name and qualifications, in resume format, for the QC Manager.
- A letter signed by an officer of the firm appointing the QC Manager and stating that he/she is responsible for implementing the QC program, as described in the contract, and referencing the QC Manager's authority to direct the removal and replacement of non-conforming work.
- Procedures for reviewing, approving and managing submittals.

- Testing laboratory information.

- A Testing Plan and Log that includes tests required, referenced by the specification paragraph number requiring the test, the frequency, and the person responsible for the test.

- Procedures to identify, record, track and complete rework items.

- Documentation procedures, including proposed report formats.

- A listing of outside organizations, such as testing laboratories, architects, and consulting engineers that will be employed by the Contractor and a description of the services these firms will provide.

- A list of the definable features of work, with a definable feature defined as a task which is separate and distinct from other tasks and which requires separate control requirements.

TABLE 1

PRE-DESIGN SAMPLING SUMMARY
SITE 01 – MCALLISTER POINT LANDFILL

ACTIVITY / SAMPLE MATRIX	SCOPE OF WORK	No. SAMPLES	SAMPLE ANALYSIS
TEST BORINGS	4 Locations each approximately 25 feet deep	4 Samples of native soil underlying the fill	• Incremental Consolidation Test (ASTMD–2435) • Triaxial Compression Test with pore pressure measurements (ASTMD–4785) • Organic Content by Burning (ASTMD–2974) • Combined Sieve and Hydrometer Analysis (ASTMD–422) • Atterburg Limits (ASTMD–4318) • Specific Gravity (ASTMD–854)
VAPOR WELLS AND VAPOR PROBES	3 Vapor Wells & 9 Vapor Probes	8 Landfill Gas Samples	• Methane Content and Organic Solvent Scan by GC/MS
SEDIMENT SAMPLES	6 locations from the area at the base of the landfill slope where shoreline protection will be placed and existing sediment removed	6 Sediment Samples 4 Sediment Samples	• Grain Size, Moisture Content, Total Solids, TOC, Specific Gravity, Total Sulfides, and Ammonia • Full TCLP, TCL, and TAL, TPH, and Oil & Grease

Note: TCL indicates the sample will be analyzed for Target Compound List parameters.
TAL indicates the sample will be analyzed for Target Analyte List parameters.
TCLP indicates the sample will be analyzed for Toxicity Characteristic Leaching Procedure parameters.
TPH indicates the sample will be analyzed for Total Petroleum Hydrocarbons.
TOC indicates the sample will be analyzed for Total Organic Carbon.

TABLE 2
PHASE I CONTAMINANTS OF CONCERN
MCALLISTER POINT LANDFILL

SOIL	**GROUND WATER**
Semivolatiles	Semivolatiles
Carcinogenic PAHs	Naphthalene 2-Methylnapthalene 1,4-Dichlorobenzene
Inorganics	Inorganics
Antimony Arsenic Beryllium Copper Lead Zinc	Antimony Arsenic Beryllium Cadmium Chromium Copper Lead Manganese Mercury Zinc
Volatiles	Volatiles
	Benzene Ethylbenzene Toluene Xylene

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TABLE 3
SITE 01 - McALLISTER POINT LANDFILL
PERSONNEL PROTECTION SUMMARY

Activity	*Initial Level of Protection*
Reconnaissance Survey	*D*
Soil Boring	*Mod. D*
Sediment Sampling	*Mod. D*
Landfill Gas Pilot Study	*C*

NOTE: *The personnel protection levels will be upgraded or downgraded as conditions warrant according to criteria specified in the project Health and Safety Plan (HASP).*

TABLE 4
SITE 01 - McALLISTER POINT LANDFILL
SITE EMERGENCY CONTACTS

NETC Emergency Numbers:

Command Duty Officer	841-3456 or 3457
Security Office - Police	841-3241
NETC Fire Protection	841-3333
Public Works Trouble Desk	841-4001

Utilities:

NETC Dig Safe	841-2464
Rhode Island Dig Safe	800-225-4977

Newport Emergency Numbers:

Newport Police Department	847-1306
Newport Fire Department	846-2211
Newport Hospital	
General Number	846-6400
Emergency Room	846-6400 ext 1120
Poison Control Center	277-5727

Additional Resources:

Dr. Erdil - TRC Company physician	
Immediate Medical Care	
Hartford, Connecticut	(203) 296-8330
Mr. James Peronto - TRC	(203) 289-8631
Mr. Brad Wheeler - NETC	(401) 841-3735

TABLE 5
CONTAINERS AND PRESERVATION METHODS
FOR SOIL, SEDIMENT, AND LANDFILL GAS SAMPLES

Number Containers per Sample	Sample Container	Preservation Methods[a]	Analytical Method	Compounds
Organics				
2	125 ml, wide-mouth glass, Teflon -lined cap	Cool, 4oC	CLP SOW	TCL VOA
1	1-250 ml, wide-mouth amber glass, Teflon -lined cap	Cool, 4oC	CLP SOW	TCL-BNA, Pest/PCB
1	1-125 ml, wide-mouth glass Teflon -lined cap	Cool, 4oC	EPA 1311	TCLP
1	1-125 ml, wide-mouth glass Teflon -lined cap	Cool, 4oC	EPA 418.1	Total Petroleum Hydrocarbons
1	1-950 ml, wide-mouth amber glass Teflon -lined cap	Cool, 4oC	EPA 413.1	Oil & Grease
Inorganics				
1	250-ml, wide-mouth glass, Teflon -lined cap	Cool, 4oC	CLP SOW[b]	Metals
1	1000 ml, wide-mouth glass	NA	ASTMD422-63	Grain Size
1	500 ml, wide-mouth glass, Teflon-lined cap	Cool, 4oC	SW 9060, EPA 376.1, EPA 350.1	TOC, Total Sulfides, Ammonia
Landfill Gas				
1	6-liter Tedlar bag	Dark, Cool	GC/MS Modified T01/T02	VOCs

VOA = Volatile Organic Analyses.
TCL = Target Compound List.
BNA = Base Neutral and Acid Extractable Analyses.
Pest/PCB = Pesticide/PCB Analyses.
TCLP = Toxicity Characteristic Leaching Procedure (VOCs, SVOCs, Herb., Pest., PCBs).
CLP SOW = Contract Laboratory Program - Statement of Work.
Organics - SOW 3/90, revised July 1991.
Inorganics - SOW 3/90, revised September 1991.

(a) Samples will be stored in a refrigerated, dark area.

(b) Metals analyses, except mercury, will be performed by the furnace atomic absorption (As, Pb, Se, Tl) and inductively coupled plasma (ICP) atomic emission spectrometric methods. Mercury will be analyzed by the manual cold vapor atomic absorption method.

TABLE 6
HOLDING TIMES FOR SOIL AND SEDIMENT SAMPLES

Parameter	CLP Holding Time for Samples: Aqueous	CLP Holding Time for Samples: Soil/Sediment/Waste
TCL Volatile Organic Compounds	10 days from VTSR	10 days from VTSR
TCL Base Neutral/Acid Extractable Compounds	5 days to extraction from VTSR; 40 days from extraction	7 days[1] extraction from VTSR; 40 days from extraction
TCL Pesticide/PCB Compounds	5 days to extraction; 40 days from extraction	7 days[1] to extraction; 40 days from extraction
Total Petroleum Hydrocarbons	28 Days[2]	28 Days
TAL Metals	6 months; except Hg - 26 days	6 months; except Hg - 26 days
TOC	28 Days[2]	28 Days
Total Sulfides	7 days	NE
Ammonia (Nitrogen)	28 days	NE

NE = Not Established; no holding times established according to the CLP SOW or applicable methods.
NA = Not Applicable.
VTSR = Verified Time of Sample Receipt.
[1] = U.S. EPA Region I requirement.
[2] = If preserved with H_2SO_4 or HCL to pH <2.

TABLE 7
TARGET COMPOUND LIST (TCL) VOLATILE COMPOUNDS AND DETECTION LIMITS

Volatiles	CAS Number	Detection Limits[a] Water (ug/l)	Detection Limits[a] Low Soil/Sediment[b] (ug/kg)
Chloromethane	74-87-3	10	10
Bromomethane	74-83-9	10	10
Vinyl chloride	75-01-4	10	10
Chloroethane	75-00-3	10	10
Methylene chloride	75-09-2	10	10
Acetone	67-64-1	10	10
Carbon disulfide	75-15-0	10	10
1,1-Dichloroethene	75-35-4	10	10
1,1-Dichloroethane	75-35-3	10	10
1,2-Dichloroethene (total)	156-60-5	10	10
Chloroform	67-66-3	10	10
1,2-Dichloroethane	107-06-2	10	10
2-Butanone	78-93-3	10	10
1,1,1-Trichloroethane	71-55-6	10	10
Carbon tetrachloride	56-23-5	10	10
Bromodichloromethane	75-27-4	10	10
1,2-Dichloropropane	78-87-5	10	10
cis-1,3-Dichloropropene	10061-01-5	10	10
Trichloroethene	79-01-6	10	10
Dibromochloromethane	124-48-1	10	10
1,1,2-Trichloroethane	79-00-5	10	10
Benzene	71-43-2	10	10
trans-1,3-Dichloropropene	10061-02-6	10	10
Bromoform	75-25-2	10	10
4-Methyl-2-pentanone	108-10-1	10	10

TABLE 7 (Continued)
TARGET COMPOUND LIST (TCL) VOLATILE
COMPOUNDS AND DETECTION LIMITS

Volatiles	CAS Number	Detection Limits[a] Water (ug/l)	Low Soil/Sediment[b] (ug/kg)
2-Hexanone	591-78-6	10	10
Tetrachloroethene	127-18-4	10	10
Toluene	108-88-3	10	10
1,1,2,2-Tetrachloroethane	79-34-5	10	10
Chlorobenzene	108-90-7	10	10
Ethyl benzene	100-41-4	10	10
Styrene	100-42-5	10	10
Total xylenes	1330-20-7	10	10

[a] Detection limits listed for soil/sediment are based on wet weight. The detection limits calculated for soil/sediment calculated on dry weight basis will be higher.

[b] Medium soil/sediment detection limits for volatile TCL compounds are 120 times the individual low soil/sediment detection limits.

Note: Specific detection limits are highly matrix dependent. The detection limits listed herein are provided for guidance and may not always be achievable.

TABLE 8
TARGET COMPOUND LIST (TCL) SEMIVOLATILE COMPOUNDS AND DETECTION LIMITS

Semivolatiles	CAS Number	Detection Limits[a] Water (ug/l)	Low Soil/Sediment[b] (ug/kg)
Phenol	108-95-2	10	330
Bis(2-chloroethyl)ether	111-44-4	10	330
2-Chlorophenol	95-57-8	10	330
1,3-Dichlorobenzene	541-73-1	10	330
1,4-Dichlorobenzene	106-46-7	10	330
1,2-Dichlorobenzene	95-50-1	10	330
2-Methylphenol	95-48-7	10	330
2,2'-oxybis(1-Chloropropane)[c]	108-60-1	10	330
4-Methylphenol	106-44-5	10	330
N-Nitroso-di-n-propylamine	621-64-7	10	330
Hexachloroethane	67-72-1	10	330
Nitrobenzene	98-95-3	10	330
Isophorone	78-59-1	10	330
2-Nitrophenol	88-75-5	10	330
2,4-Dimethylphenol	105-67-9	10	330
Bis(2-chloroethoxy)methane	111-91-1	10	330
2,4-Dichlorophenol	120-83-2	10	330
1,2,4-Trichlorobenzene	120-82-1	10	330
Naphthalene	91-20-3	10	330
4-Chloroaniline	106-47-8	10	330
Hexachlorobutadiene	87-68-3	10	330
4-Chloro-3-methylphenol (para-chloro-meta-cresol)	59-50-7	10	330
2-Methylnaphthalene	91-57-6	10	330
Hexachlorocyclopentadiene	77-47-4	10	330
2,4,6-Trichlorophenol	88-06-2	10	330
2,4,5-Trichlorophenol	95-95-4	25	800
2-Chloronaphthalene	91-58-7	10	330
2-Nitroaniline	88-74-4	25	800

TABLE 8 (Continued)
TARGET COMPOUND LIST (TCL) SEMIVOLATILE
COMPOUNDS AND DETECTION LIMITS

Semivolatiles	CAS Number	Detection Limits[a] Water (ug/l)	Low Soil/Sediment[b] (ug/kg)
Dimethylphthalate	131-11-3	10	330
Acenaphthylene	208-96-8	10	330
2,6-Dinitrotoluene	606-20-2	10	330
3-Nitroaniline	99-09-2	25	800
Acenaphthene	83-32-9	10	330
2,4-Dinitrophenol	51-28-5	25	800
4-Nitrophenol	100-02-7	25	800
Dibenzofuran	132-64-9	10	330
2,4-Dinitrotoluene	121-14-2	10	330
Diethylphthalate	84-66-2	10	330
4-Chlorophenyl-phenylether	7005-72-3	10	330
Fluorene	86-73-7	10	330
4-Nitroaniline	100-01-6	25	800
4,6-Dinitro-2-methylphenol	534-52-1	25	800
N-nitrosodiphenylamine	86-30-6	10	330
4-Bromophenyl-phenylether	101-55-3	10	330
Hexachlorobenzene	118-74-1	10	330
Pentachlorophenol	87-86-5	25	800
Phenanthrene	85-01-8	10	330
Anthracene	120-12-7	10	330
Carbazole	86-74-8	10	330
Di-n-butylphthalate	84-74-2	10	330
Fluoranthene	206-44-0	10	330
Pyrene	129-00-0	10	330
Butylbenzylphthalate	85-68-7	10	330
3,3'-Dichlorobenzidine	91-94-1	10	330

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TABLE 8 (Continued)
TARGET COMPOUND LIST (TCL) SEMIVOLATILE COMPOUNDS AND DETECTION LIMITS

Semivolatiles	CAS Number	Detection Limits[a] Water (ug/l)	Low Soil/Sediment[b] (ug/kg)
Benzo(a)anthracene	56-55-3	10	330
Chrysene	218-01-9	10	330
Bis(2-ethylhexyl)phthalate	117-81-7	10	330
Di-n-octylphthalate	117-84-0	10	330
Benzo(b)fluoranthene	205-99-2	10	330
Benzo(k)fluoranthene	207-08-9	10	330
Benzo(a)pyrene	50-32-8	10	330
Indeno(1,2,3-cd)pyrene	193-39-5	10	330
Dibenzo(a,h)anthracene	53-70-3	10	330
Benzo(g,h,i)perylene	191-24-2	10	330

(a) Detection limits listed for soil/sediment are based on wet weight. The detection limits calculated for soil/sediment calculated on dry weight basis will be higher.

(b) Medium soil/sediment detection limits for semivolatile TCL compounds with a low detection limit of 330 ug/kg are 10,000 ug/kg; for semivolatiles with a low detection limit of 800 ug/kg, they are 25,000 ug/kg.

(c) Previously known by the name bis(2-chloroisopropyl)ether.

Note: Specific detection limits are highly matrix dependent. The detection limits listed herein are provided for guidance and may not always be achievable.

TABLE 9
TARGET COMPOUND LIST (TCL) PESTICIDES, PCBs, AND DETECTION LIMITS

Detection Limits[a]

Pesticides/PCBs	CAS Number	Water (ug/l)	Soil/Sediment[b] (ug/kg)
alpha-BHC	319-84-6	0.05	1.7
beta-BHC	319-85-7	0.05	1.7
delta-BHC	319-86-8	0.05	1.7
gamma-BHC (Lindane)	58-89-9	0.05	1.7
Heptachlor	76-44-8	0.05	1.7
Aldrin	309-00-2	0.05	1.7
Heptachlor epoxide	1024-57-3	0.05	1.7
Endosulfan I	959-98-8	0.05	1.7
Dieldrin	60-57-1	0.10	3.3
4,4'-DDE	72-55-9	0.10	3.3
Endrin	72-20-8	0.10	3.3
Endosulfan II	33213-65-9	0.10	3.3
4,4'-DDD	72-54-8	0.10	3.3
Endosulfan sulfate	1031-07-8	0.10	3.3
4,4'-DDT	50-29-3	0.10	3.3
Methoxychlor	72-43-5	0.50	17.0
Endrin ketone	53494-70-5	0.10	3.3
Endrin aldehyde	7421-93-4	0.10	3.3
alpha-Chlordane	5103-71-9	0.05	1.7
gamma-Chlordane	5103-74-2	0:05	1.7
Toxaphene	8001-35-2	5.0	170.0
AROCLOR-1016	12674-11-2	1.0	33.0
AROCLOR-1221	11104-28-2	2.0	67.0
AROCLOR-1232	11141-16-5	1.0	33.0
AROCLOR-1242	53469-21-9	1.0	33.0
AROCLOR-1248	12672-29-6	1.0	33.0
AROCLOR-1254	11097-69-1	1.0	33.0
AROCLOR-1260	11096-82-5	1.0	33.0

[a] Detection limits listed for soil/sediment are based on wet weight. The detection limits calculated for soil/sediment calculated on dry weight basis will be higher.

[b] There is no differentiation between the preparation of low and medium soil samples in this method for the ?analysis of pesticides/aroclors.

Note: Specific detection limits are highly matrix dependent. The detection limits listed herein are provided for guidance and may not always be achievable.

TABLE 10
SURROGATE SPIKE RECOVERY RANGE

Fraction	Surrogate Compounds	Water % Recovery	Soil/Sediment % Recovery
Volatiles	Toluene-d_8	88-110	84-138
	Bromofluorobenzene	86-115	59-113
	1,2-Dichloroethane-d_4	76-114	70-121
Semi-Volatiles	Nitrobenzene-d_5	35-114	23-120
	2-Fluorobiphenyl	43-116	30-115
	Terphenyl-d_{14}	33-141	18-137
	Phenol-d_5	10-110	24-113
	2-Fluorophenol	21-110	25-121
	2,4,6-Tribromophenol	10-123	19-122
	2-Chlorophenol-d_4	33-110	(20-130)[a]
	1,2-Dichlorobenzene-d_4	16-110	(20-130)[a]
Pesticides	Tetrachloro-m-xylene	(60-150)[a]	(60-150)[a]
	Decachlorobiphenyl	(60-150)[a]	(60-150)[a]

[a] Advisory limits only

TABLE 11
TARGET ANALYTE LIST (TAL) INORGANICS AND CONTRACT REQUIRED DETECTION LIMITS (CRDL)[(a)]

Element	Detection Limit: Water (ug/l)	Detection Limit: Low Soil/Sediment (ug/g)
Aluminum	200	40
Antimony	60	12
Arsenic	10	2
Barium	200	40
Beryllium	5	1
Cadmium	1.5[c]	1
Calcium	5,000	1,000
Chromium	10	2
Cobalt	50	10
Copper	12[d]	5
Iron	100	20
Lead	3	1
Magnesium	5,000	1,000
Manganese	15	3
Mercury	0.05[e]	0.1[b]
Nickel	40	8
Potassium	5,000	1,000
Selenium	5	1
Silver	1[c]	2
Sodium	5,000	1,000
Thallium	10	2
Vanadium	50	10
Zinc	20	4
Cyanide	10	1

(a) Specific detection limits are highly matrix dependent. The detection limits listed herein are provided for guidance and may not always be achievable. Soil/sediment CRDLs are based on sample wet weights. Dry weight CRDLs will depend on the moisture content of the individual samples.

b Different aliquot.

c Obtain CRDL by using Graphite Furnace Atomic Absorption (AA).

d Obtain CRDL by using Inductively Coupled Plasma (ICP).

e Obtain CRDL by using Cold Vapor Atomic Absorption (AA).

TABLE 12
LANDFILL GAS COMPOUNDS

Compound List	CAS No.
Methyl-t-Butyl Ether	1634-04-4
Chloroform	67-66-3
Methyl Chloroform	71-55-6
Cyclohexane	110-82-7
Carbon Tetrachloride	56-23-5
n-Heptane	182-82-5
Benzene	71-43-2
1,2-Dichloroethane	107-06-2
Trichloroethene	79-01-6
1,2-Dichloropropane	78-87-5
Toluene	108-88-3
Tetrachloroethene	127-18-4
Ethylene Dibromide	106-93-4
Chlorobenzene	108-90-7
Ethyl Benzene	100-41-4
o-Xylene	95-47-6
1-Methylethyl Benzene	98-82-8
Bromoform	75-25-2
Benzyl Chloride	100-44-7
o-Chlorotoluene	106-43-4
0-Dichlorobenzene	106-46-7

Notes: The above listed compounds are used as calibration standards for Environmental Health Laboratories of Cromwell Connecticut for Modified EPA Methods T01/T02 analyses (August 1993).

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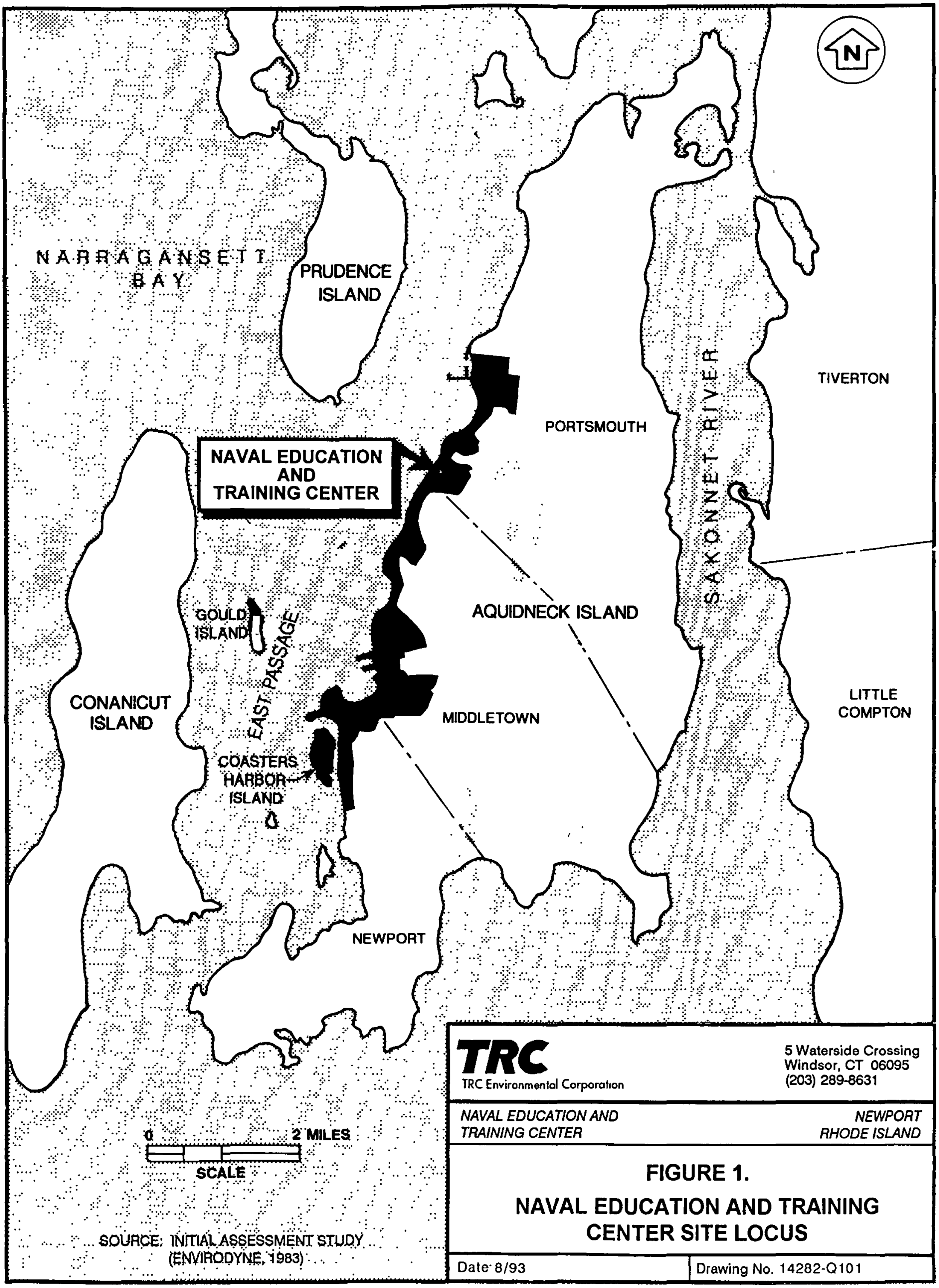


FIGURE 1.

NAVAL EDUCATION AND TRAINING CENTER SITE LOCUS

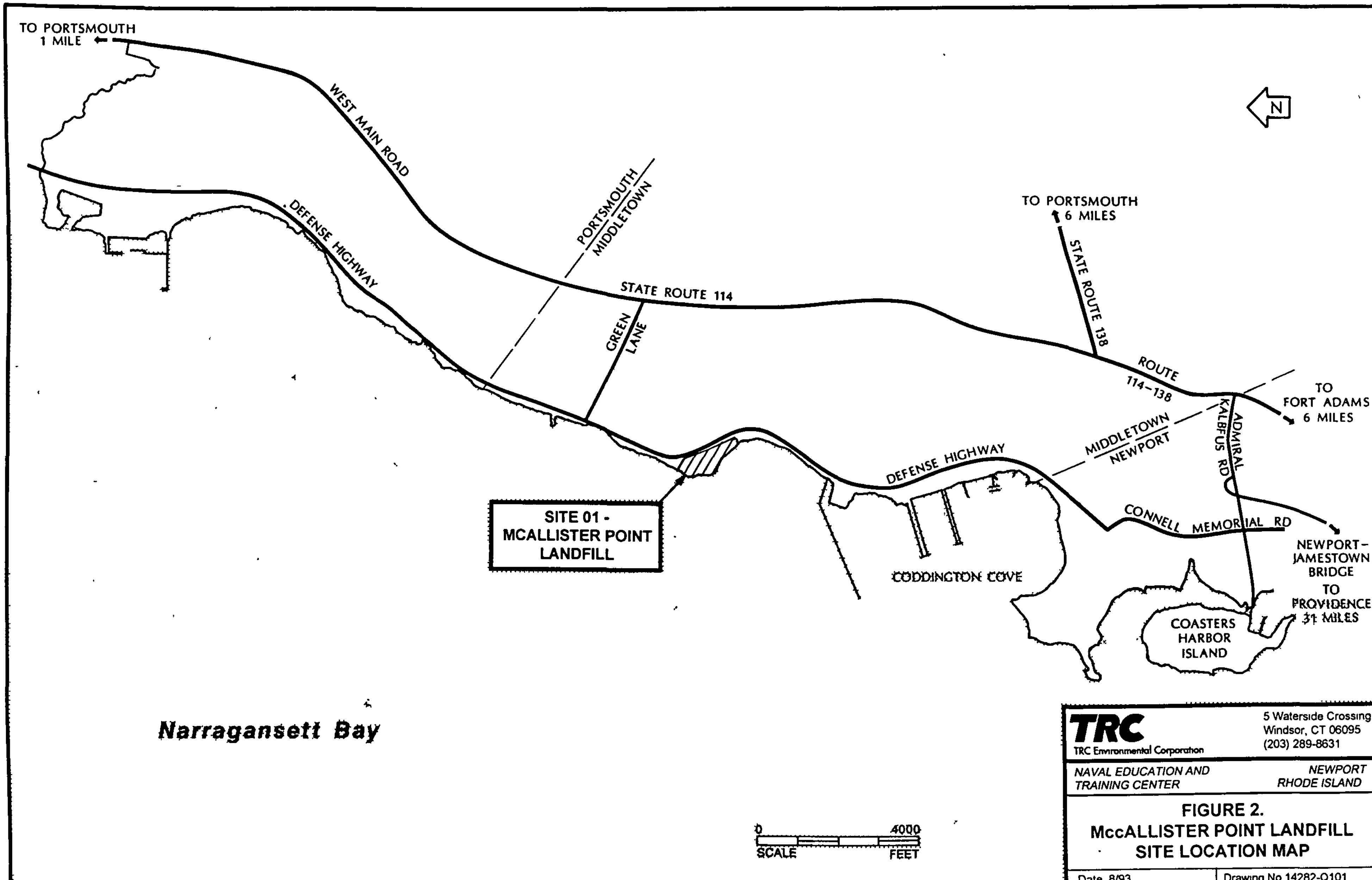
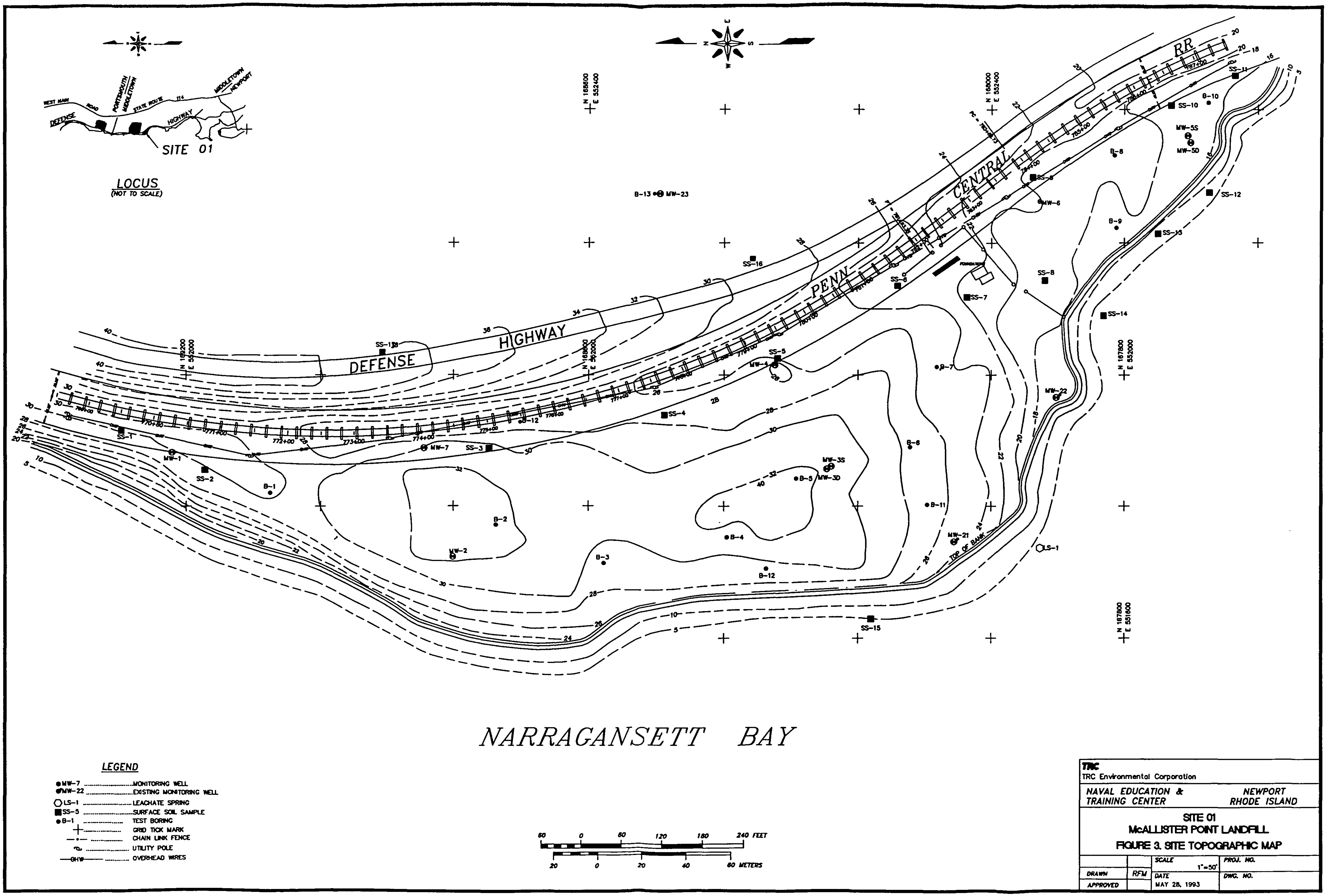


FIGURE 2.
McALLISTER POINT LANDFILL
SITE LOCATION MAP


LOCUS
(NOT TO SCALE)
SITE 01
DEFENSE HIGHWAY
PENN CENTRAL RR
NARRAGANSETT BAY
TOP OF BANK
LEGEND
MW-7 MONITORING WELL
MW-22 EXISTING MONITORING WELL
LS-1 LEACHATE SPRING
SS-5 SURFACE SOIL SAMPLE
B-1 TEST BORING
GRID TICK MARK
CHAIN LINK FENCE
UTILITY POLE
OHW OVERHEAD WIRES
60 0 60 120 180 240 FEET
20 0 20 40 60 METERS
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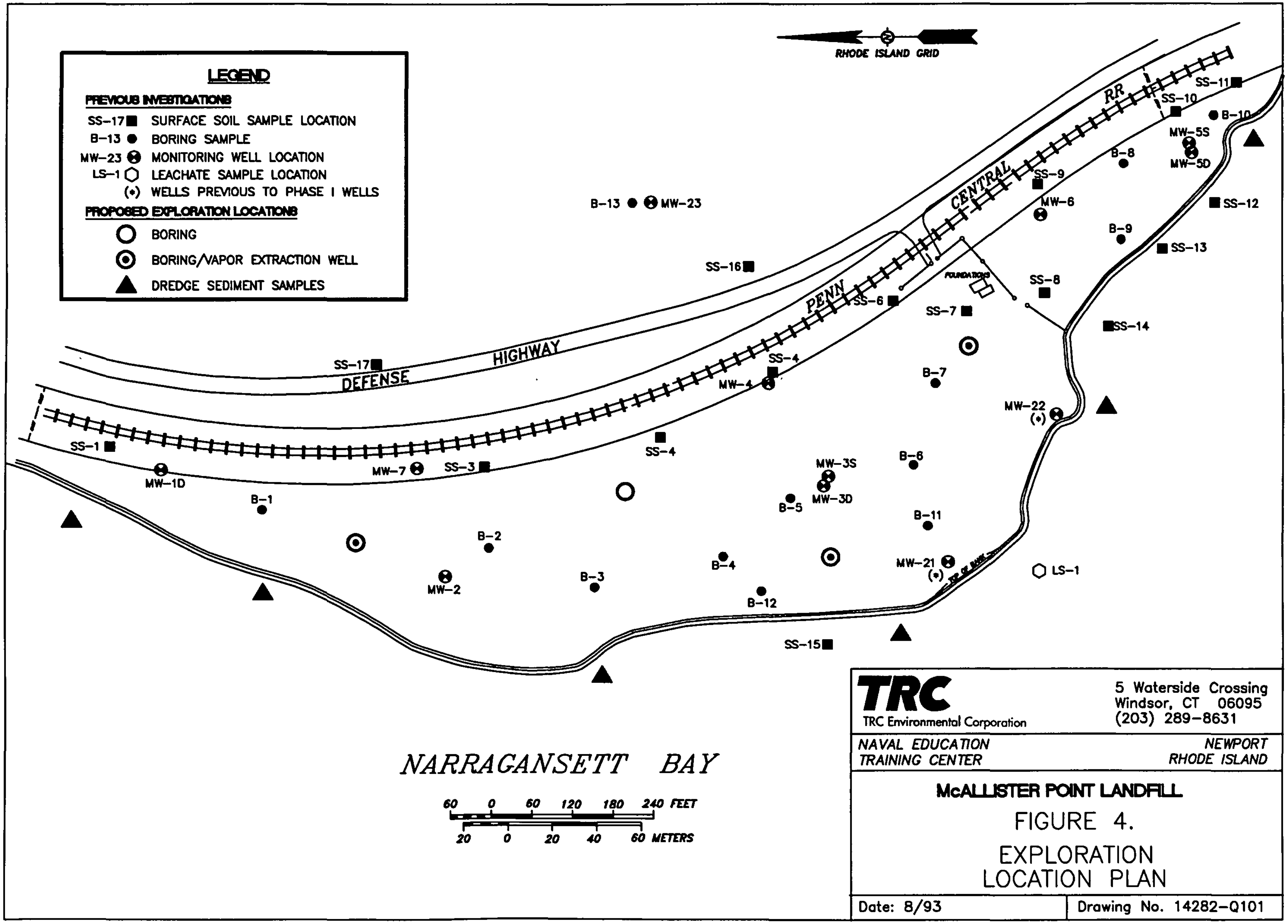
NAVAL EDUCATION & TRAINING CENTER
NEWPORT RHODE ISLAND
SITE 01
McALLISTER POINT LANDFILL
FIGURE 3. SITE TOPOGRAPHIC MAP
SCALE 1"=50'
PROJ. NO.
DRAWN RFM
DATE MAY 28, 1993
DWG. NO.
APPROVED



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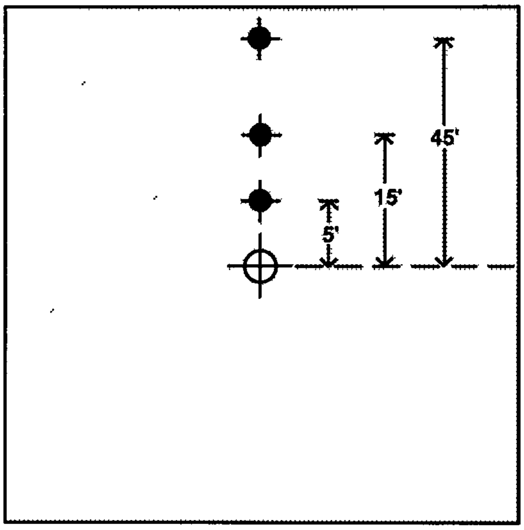
McALLISTER POINT LANDFILL

FIGURE 4.

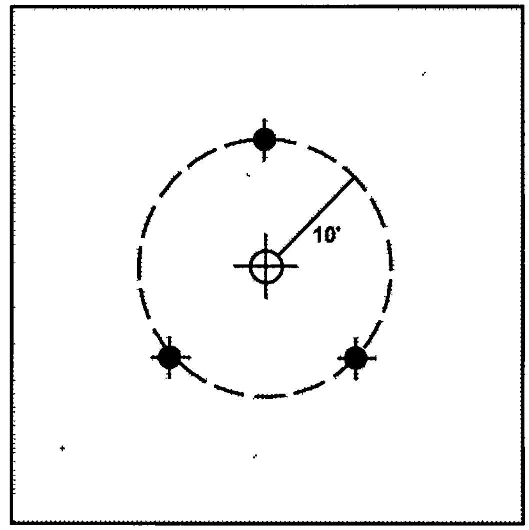
EXPLORATION LOCATION PLAN

Date: 8/93 | Drawing No. 14282-Q101

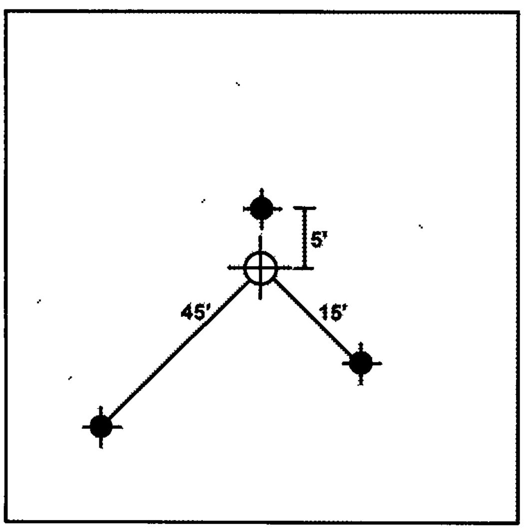
LANDFILL GAS MONITORING
NETWORK A



LANDFILL GAS MONITORING
NETWORK B



LANDFILL GAS MONITORING
NETWORK C



LEGEND

GAS EXTRACTION WELL

VAPOR PROBE

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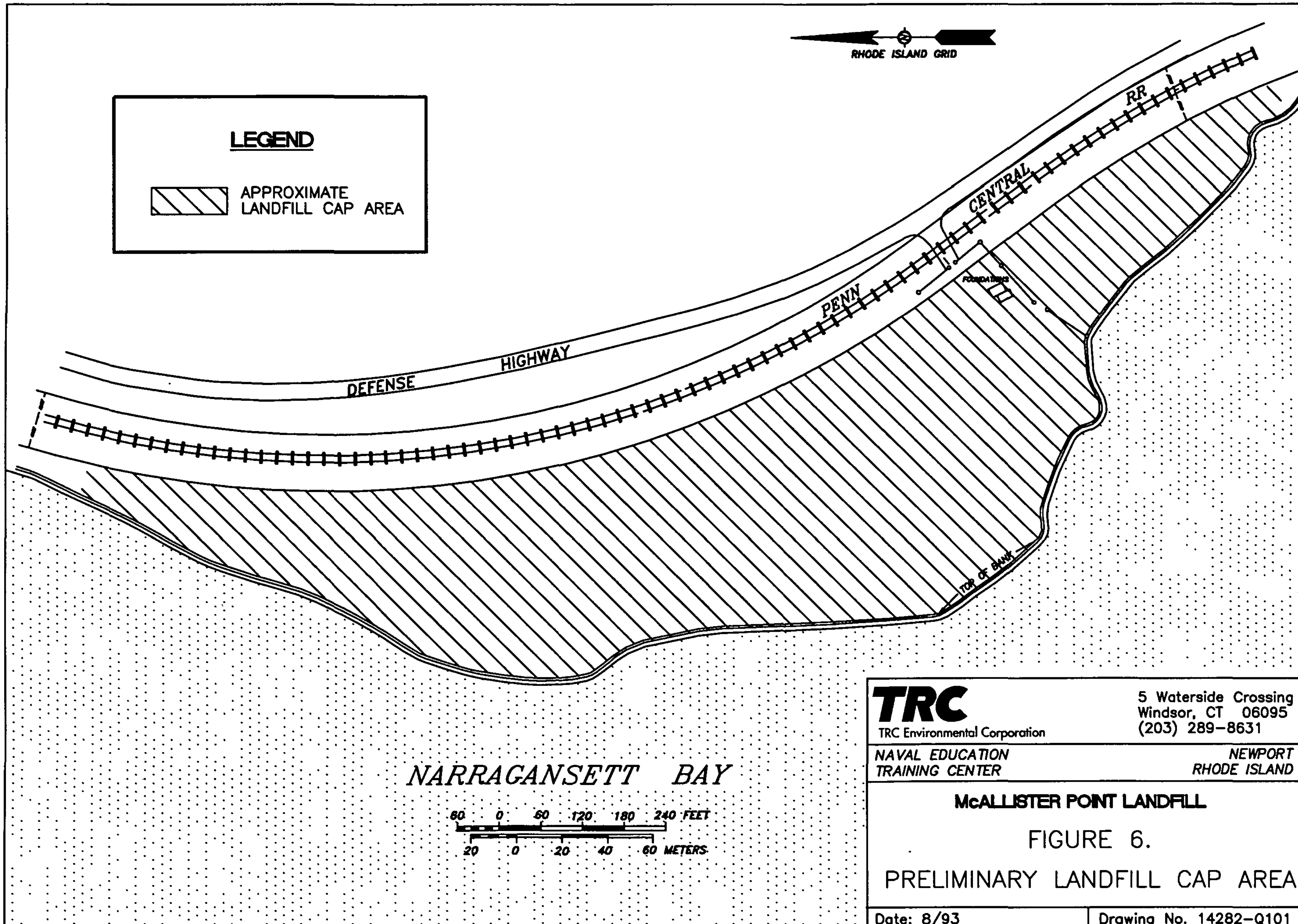
FIGURE 5.

LANDFILL GAS PROBE CONFIGURATIONS

Date: 8/93 | Drawing No 14282-Q101



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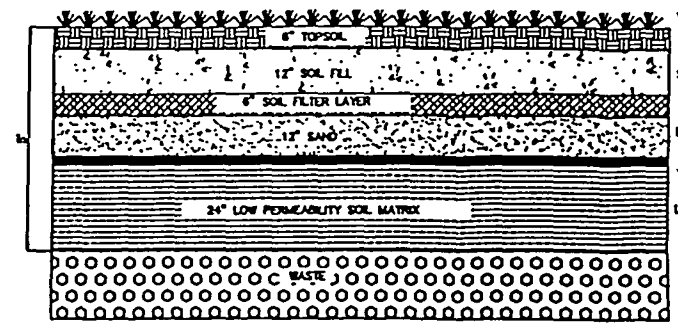
McALLISTER POINT LANDFILL

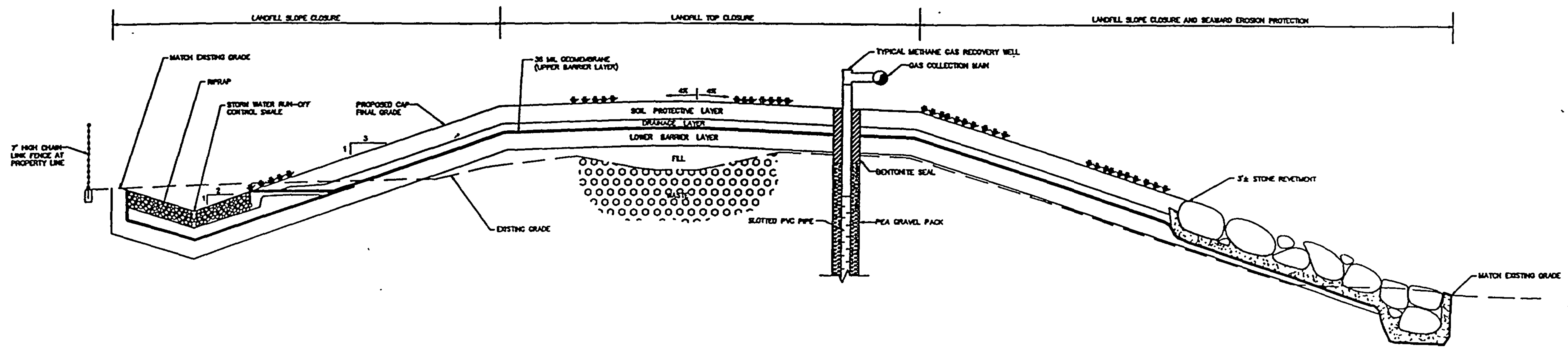
FIGURE 6.

PRELIMINARY LANDFILL CAP AREA

Date: 8/93 | Drawing No. 14282-Q101



CAP DETAIL
NOT TO SCALE



TYPICAL SECTION THROUGH LANDFILL CAP
NOT TO SCALE

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FIGURE 7.
McALLISTER POINT LANDFILL
CONCEPTUAL CAP DETAILS

Date: 8/93	Drawing No. 14282-Q101

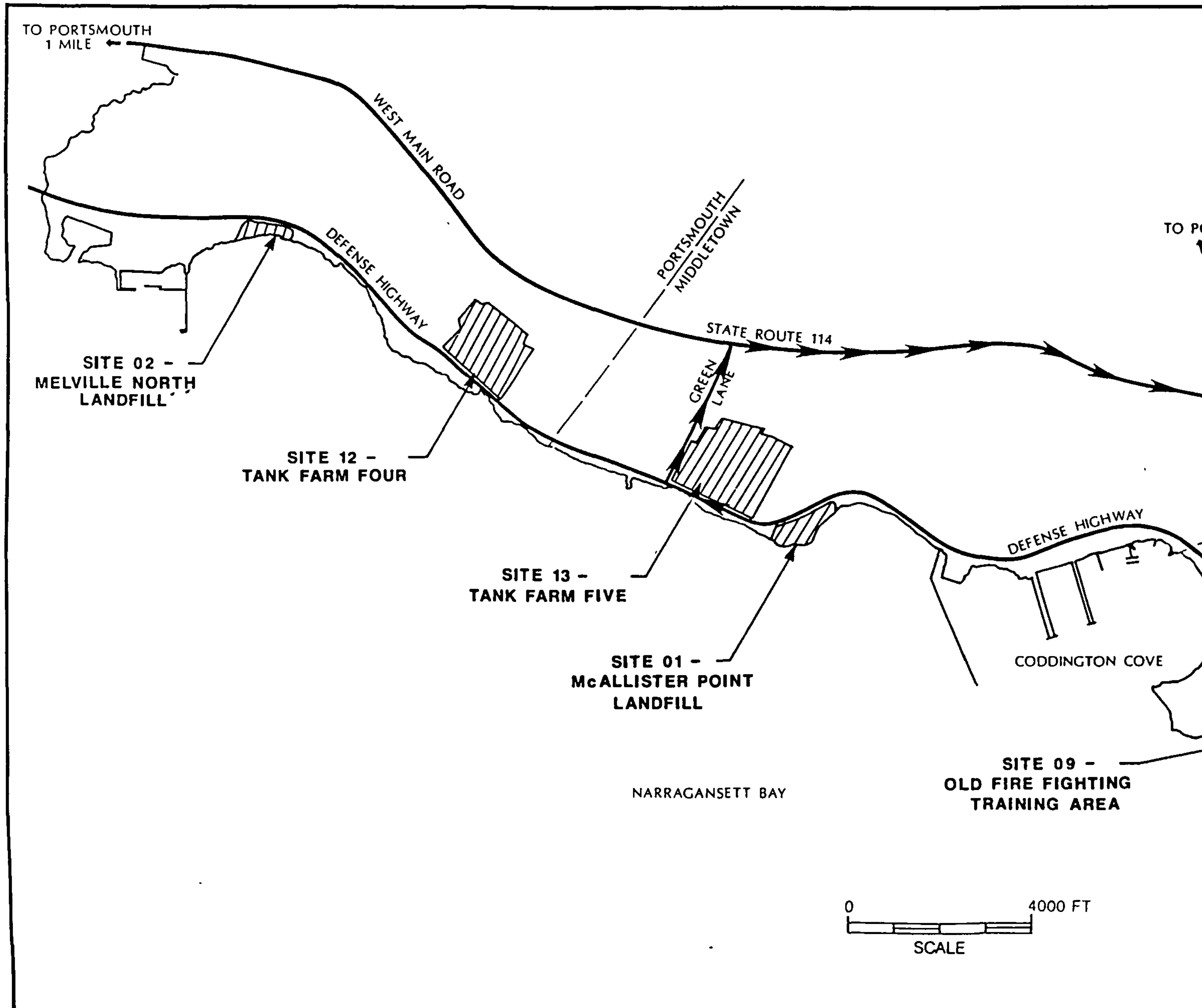

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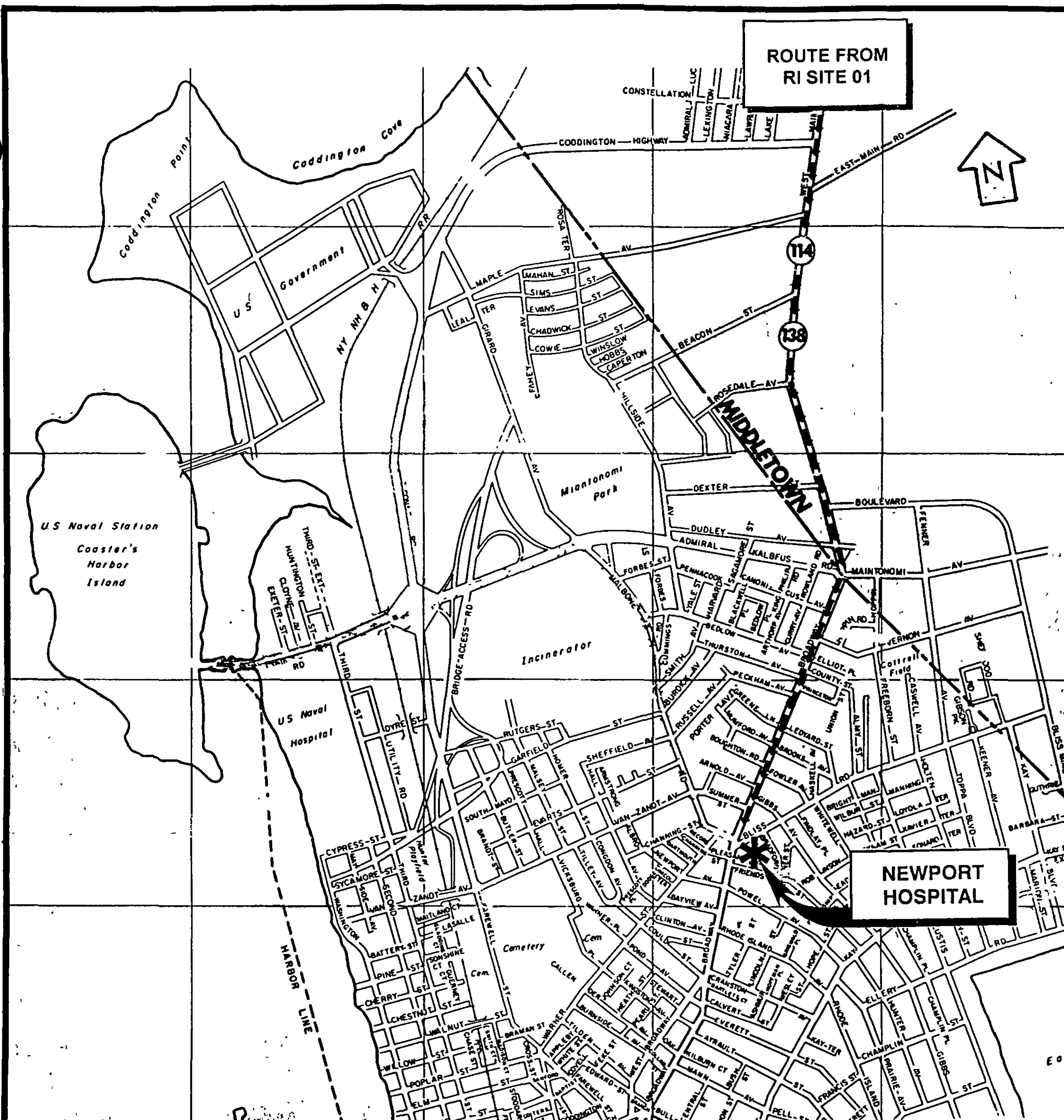
FIGURE 8.

NEWPORT HOSPITAL ROUTE MAP

Date 8/93 | Drawing No 14282-Q101



0 1/4 1/2
SCALE IN MILES

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NEWPORT RHODE ISLAND

FIGURE 8A.

NEWPORT HOSPITAL ROUTE MAP

Date 8/93	Drawing No.14282-Q101

TRC Environmental Corporation

CHAIN OF CUSTODY RECORD

PROJECT NO.	PROJECT NAME	PARAMETERS	Nº 2043

SAMPLERS: *(Signature)*	(Printed)

FIELD SAMPLE NUMBER	DATE	TIME	COMP.	GRAB	STATION LOCATION	NO. OF CONTAINERS									REMARKS

Relinquished by: *(Signature)*	Date / Time	Received by: *(Signature)*	Relinquished by: *(Signature)*	Date / Time	Received by: *(Signature)*
(Printed)		(Printed)	(Printed)		(Printed)

Relinquished by: *(Signature)*	Date / Time	Received for Laboratory by: *(Signature)*	Date / Time	Remarks
(Printed)		(Printed)		

Distribution: Original Plus One Accompanies Shipment (white and yellow), Copy to Coordinator Field Files (pink).

FIGURE 9. CHAIN OF CUSTODY RECORD

APPENDIX A

FIELD SAMPLING METHODOLOGY PLAN

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U.S. DEPARTMENT OF THE NAVY
INSTALLATION RESTORATION PROGRAM

APPENDIX A
FIELD SAMPLING METHODOLOGY PLAN

SITE 01 - MCALLISTER POINT LANDFILL CAP
NAVAL EDUCATION AND TRAINING CENTER,
NEWPORT, RHODE ISLAND

Prepared for:
Northern Division
Naval Facilities Engineering Command
Lester, Pennsylvania

August 1993

TRC-EC Project No. 14282-Q101-01
Contract No. N62472-86-C-1282

TRC

TABLE OF CONTENTS

1.0 AMBIENT SURVEYS

Ambient surveys provide a means of measuring concentrations of volatile organic compounds, and combustible gases and oxygen during field exploration activities. Data produced from ambient surveys provide "real time" data from which field personnel may monitor site hazards, and act accordingly.

The following two ambient survey techniques will be used throughout the course of the pre-design investigations at the landfill.

- Volatile Organic Compound Survey
- Combustible Gas and Oxygen Survey

1.1 VOLATILE ORGANIC COMPOUND SURVEY

An ambient air monitoring program will be conducted prior to and during field exploration activities. An OVA Flame Ionization detector (FID) (Century Organic Vapor Analyzer OVA 128, or equivalent) and/or a photoionization detector (PID) (HNu Model PI-101 Photoanalyzer with 10.2 eV lamp, or equivalent) will be used to survey the site area prior to sampling activities to site background conditions. During the test boring and sampling activities these instruments will also be used to continuously monitor ambient and sample concentrations for the presence of volatile organic vapors.

Since instruments performing measurements have inherent limitations arising from equipment limitations (fluctuations or drift) and changes in ambient conditions, instrument adjustments may be required to maintain their calibration. Calibration checks of the HNu and OVA will be preformed a minimum of twice per day (at the beginning and end of each day). The OVA and HNu will be calibrated with a hydrocarbon-free "zero" gas and a known hydrocarbon concentration. The OVA and HNu calibration gases consist of concentrations of 10 ppm methane in air and approximately 54 ppm isobutylene in air, respectively. Changes in instrument settings will be noted in the field notebooks under instrument calibration.

1.2 COMBUSTIBLE GAS AND OXYGEN SURVEY

Prior to initiating site exploration activities, the landfill will be screened for combustible gases and oxygen with a combination combustible gas (lower explosive limit - LEL) and oxygen (O_2) meter. During subsurface explorations, an LEL/O_2 meter will also be used continuously to measure for combustible gases and oxygen. The LEL/O_2 meter will be calibrated a minimum of twice per day (start and finish) with a pentane gas/oxygen mixture.

2.0 SEDIMENT SAMPLING

Sediment samples will be collected from along the shoreline of the landfill. The collection of sediment samples is intended to characterize the material which may be excavated for placement of shoreline protection features as required by RIDEM, Division of Water Resources for excavation activities (dredging) below the mean high water level.

2.1 SEDIMENT SAMPLING METHODS

Sediment samples will be collected with a precleaned two-inch diameter by two-foot long fiberglass hand coring device. This device will be equipped with a top mounted check valve to prevent sample washout during retrieval through the overlying water column (e.g., if a high tide) Core liners will be constructed of fiberglass or similar material. Core ends will be screened with a flame or photo-ionization detector for the presence of organic vapors immediately upon collection and all readings recorded. The portion of the core which indicates evidence of contamination (e.g. odors, discoloration, etc.) will be retained for laboratory analysis. In the absence of obvious zones of contamination, a composite sample will be retained from the entire 2-foot core. In general, sediment samples will be collected over the depth interval which may be excavated for the placement of shoreline revetment. Presently this interval is anticipated to extend from approximately two to four feet below existing ground surface. Therefore, to characterize sediment or soil conditions near the base of the excavation, a subset of sediment samples will be collected from the two to four foot deep interval. The remainder of the samples will be collected as described above, from the upper two feet of sediment.

In the event that stones or other material precludes effective use of the above sampling devices, sediment samples will be collected with a spade and spoon. All sediment samples (except VOC aliquot) will be thoroughly mixed in a stainless steel bowl prior to their placement into sample containers. Sediment sample VOC aliquots will be immediately removed from the bowl prior to mixing and placed in an appropriate sample container. Attempts will be made to remove rocks, weeds, water, and other non-sample matrix materials from the sediment sample matrix to ensure that each sediment sample contains greater than 30% solids. The physical and geologic characteristics of each sediment sample will also be recorded in a field notebook. Sample cores will be stored at approximately 4 degrees Centigrade following collection and VOC screening.

2.2 SEDIMENT SAMPLE DESIGNATIONS

Sediment samples submitted for laboratory analyses will be assigned a designated field identification number which will reference the site number, sample type, sample location, sample number, and sampling date. Below is an example of a sediment sample identification number:

Example: MP-SD1-040593

where:
MP = McAllister Point Landfill
SD = Sediment Sample
1 = Sample Number
100893 = Sampling Date (October 8, 1993)

3.0 TEST BORINGS

Subsurface test borings will be conducted to aid in assessing the presence and nature of subsurface soil/fill conditions at the landfill. If required by field conditions the rationale for any deviations to the McAllister Point Landfill sampling plan will be discussed with representatives of the Navy, EPA, and RIDEM prior to implementation of such modifications.

3.1 SAMPLING STRATEGY AND LOCATION

Test borings will be drilled and sampled to aid in assessing subsurface soil characteristics and the nature of soil contamination at individual sites. When appropriate, site background information and the findings and results of previous investigations were used in establishing the test boring plan.

3.2 SUBSURFACE SOIL BORING AND SAMPLING METHODS

Split spoon soil samples will be collected at 2.0-foot intervals from each borehole. Standard penetration tests [ASTM D1586-84 (1984)] will be conducted for every 2.0-foot sampling interval. The physical characteristics of each soil sample will be geologically logged and generally described in a field notebook. General observations which may be described include staining, odors, fill material, and wastes. Soil samples to be submitted for laboratory analyses will be transferred from the split spoon to the sample container with a dedicated stainless-steel spoon. The portion of the sample which will be analyzed for VOCs will be transferred directly into sample container(s). All other analytical fractions will be homogenized prior to filling sampling containers. Sampling equipment (e.g., augers, drilling rods, spoons) will be decontaminated prior to each use as described in the quality assurance/quality control portion of the Work Plan. Split spoon soil samples will be monitored for the presence of total VOC vapors with an organic vapor analyzer immediately upon opening. Field observations will be recorded in a field notebook.

At sites or boring locations open to the public, test borings will be backfilled to within 1.0 foot of the ground surface, after which a cement-bentonite grout will be used to "top-off" the hole to minimize potential future human exposure to contaminated drill cuttings. Remaining drill cuttings will be handled as described in the Investigation Derived Waste Plan provided as Appendix A of this Work Plan.

3.3 <u>TEST BORING SAMPLE DESIGNATION</u>

Test boring samples submitted for laboratory analyses will be assigned a designated field identification number which will reference the site number (McAllister Point Landfill - Site 01), sample type, sample location, sample number, and sampling date. Below is an example of a test boring soil sample identification number:

Example: MP-B42-041293

where:
MP = McAllister Point Landfill
B4 = Test Boring Location Number
2 = Second Sample Interval
100693 = Sampling Date (October 6, 1993)

4.0 LANDFILL GAS EXTRACTION WELLS AND VAPOR PROBES

Landfill gas extraction wells and vapor probes will be installed to aid in assessing the nature and extent of any subsurface landfill gasses which may be present at the site. In addition, these borings will be used to provide information on subsurface soil/waste characteristics.

4.1 WELL LOCATIONS

If available, information obtained from initial Phase II RI field activities (e.g., test borings, soil gas sampling, geophysical surveys) may be used to "fine tune" the final vapor extraction well locations at the site, as justified by the information.

4.2 WELL BORING, DRILLING AND SOIL SAMPLING METHODS

The boreholes for extraction wells will be advanced using 8-inch minimum inside diameter (I.D.) hollow-stem augers. Vapor probes will be advanced using minimum 4 1/4-inch ID hollow-stem augers. Split spoon samples will be collected in vapor extraction wells at five-foot intervals from ground surface until the split-spoon refusal (encountered boulders or bedrock). The split-spoons will be advanced according to the standard penetration test method [ASTM 1586-84 (1984)]. The standard penetration test defines split-spoon refusal as less than six inches of penetration for 100 blows with a 140 pound hammer falling 30 inches in conformance with ASTM 1586-84. The physical characteristics of each soil sample will be visually characterized and geologically described in a field notebook. Split spoon samples will also be monitored with a flame or photo-ionization detector (OVA or HNu). Observations will be recorded in the field notebook.

Soil samples to be submitted for laboratory analyses will be transferred directly from the split spoon to the sample container with a dedicated decontaminated stainless-steel spoon. Sampling equipment (e.g., augers, drilling rods, split-spoons) will be decontaminated prior to each use.

The final depth of vapor extraction wells will be assessed by TRC field personnel. Variables to be considered in establishing the final well depth will include material encountered, observed contamination, geologic material, depth to the water table, and site sampling objectives.

Well boring drill cuttings will be handled in accordance with the Investigation Derived Waste Plan described in Appendix A of this Work Plan.

4.3 EXTRACTION WELL AND VAPOR PROBE CONSTRUCTION

Drilling and well/vapor probe activities will be subcontracted to a qualified well drilling firm. On-site drilling activities will be conducted under the supervision of a TRC geologist/engineer.

Landfill gas extraction well construction specifications for this project include the following:

- Twelve inch borehole (minimum);
- Four-inch inside diameter PVC riser and screen;
- Threaded or press joints only on PVC pipe (no glued joints);
- Silica (quartz) sand backfill to one foot above the screened interval;
- Two foot minimum thick bentonite seal above the sand pack;
- All casing sealant and drilling fluids will be mixed with potable water;
- Vented well cap; and
- Steel casing with a locking cap will be securely set in cement over the well casing stick up and a minimum of three feet below the ground surface. Wells will be clearly numbered on casing.

A typical gas extraction well is shown in Figure A-1.

Consistent with State of Rhode Island ground water regulations (even though these are vapor extraction wells); the joints on PVC well material will be fitted with an "O" ring or wrapped with teflon tape. The well screen slot size shall retain at least 90% of the grain size of the filter pack. A bottom cap and a sump sediment trap shall be installed. The ground surface seal will be flared such that the diameter at the top is greater than the diameter at the bottom. The top of the ground surface seal shall be sloped away from the well casing and shall be imprinted with the designation of the monitoring well.

Well screen and riser lengths may vary for each extraction well. In general, screen lengths for extraction wells will extend from approximately four to five feet below ground surface to two to three feet above the highest daily ground water elevation. Well riser lengths will be field-determined so the top of the casing extends approximately one to two feet above the ground surface for wells with stick-up protective casing and approximately four to six inches below grade for wells with flush-mounted curb boxes. The driller and TRC geologist/engineer will maintain accurate written logs of the well construction details.

The vapor probe drilling activities will be performed by the drilling subcontractor under the supervision of a TRC geologist/engineer. Construction specifications for the vapor probes includes the following:

- 3-inch borehole (minimum);
- 1-inch inside diameter PVC riser;
- Threaded or pressed joints only on PVC pipe (no glued joints);
- Silica (quartz) sand backfill to 1 foot above the screened interval;
- 2-foot thick bentonite seal above the sand pack;
- Backfill drilling materials to 2 feet below ground surface;
- Portland cement grout to surface;
- Vented cap; and
- Vapor Probe numbers will be clearly labelled on the casing.

A typical vapor probe well is shown in Figure A-2.

5.0 LANDFILL GAS SAMPLING

5.1 LANDFILL GAS SAMPLING METHODS

Gas samples will be collected from each vapor probe using Tedlar gas sample bags in accordance with EPA Method 18, as indicated on Figure A-3. Using this method, the Tedlar bag is directly connected to the 1/4" Teflon gas well sample line, which eliminates the potential for ambient air infiltration through plumbing leaks.

Prior to sampling, the well will be purged of two well volumes of air. The Tedlar sampling bags will be at least six liters in volume to provide adequate sample for each screening analysis, as well as the laboratory quality control analysis. Duplicate samples will be collected on select samples as a backup in the event of bag leakage.

5.2 LANDFILL GAS SAMPLE DESIGNATION

Landfill gas samples submitted for laboratory analyses will be assigned a designated field identification number which will reference the site number (McAllister Point Landfill - Site 01), vapor probe network, sample location, sample number, and sampling date. Below is an example of a landfill gas sample identification number:

Example: MP-VPA-1-041293

where:
MP = McAllister Point Landfill
VPA = Vapor Probe Network A
1 = Probe location 1
100693 = Sampling Date (October 6, 1993)

6.0 LAND SURVEYING

Following the completion of field exploration activities the site will be surveyed by a State of Rhode Island registered surveyor. The physical site features will be reproduced on a topographic site plan (40 scale) with a one-foot contour interval from mean low water to the Defense Highway. Cross sections of the project area will be surveyed at 100-foot intervals. Shots will be taken along the cross sections at every 50 feet and at major topographic breaks. Wetlands flagging will be identified on the site topographic plan. In addition, three recoverable points will be established at the landfill with set horizontal and vertical coordinates. All elevations will be referenced to a United States Geological Survey benchmark - mean low water level (mlw) to the nearest 0.01 foot.

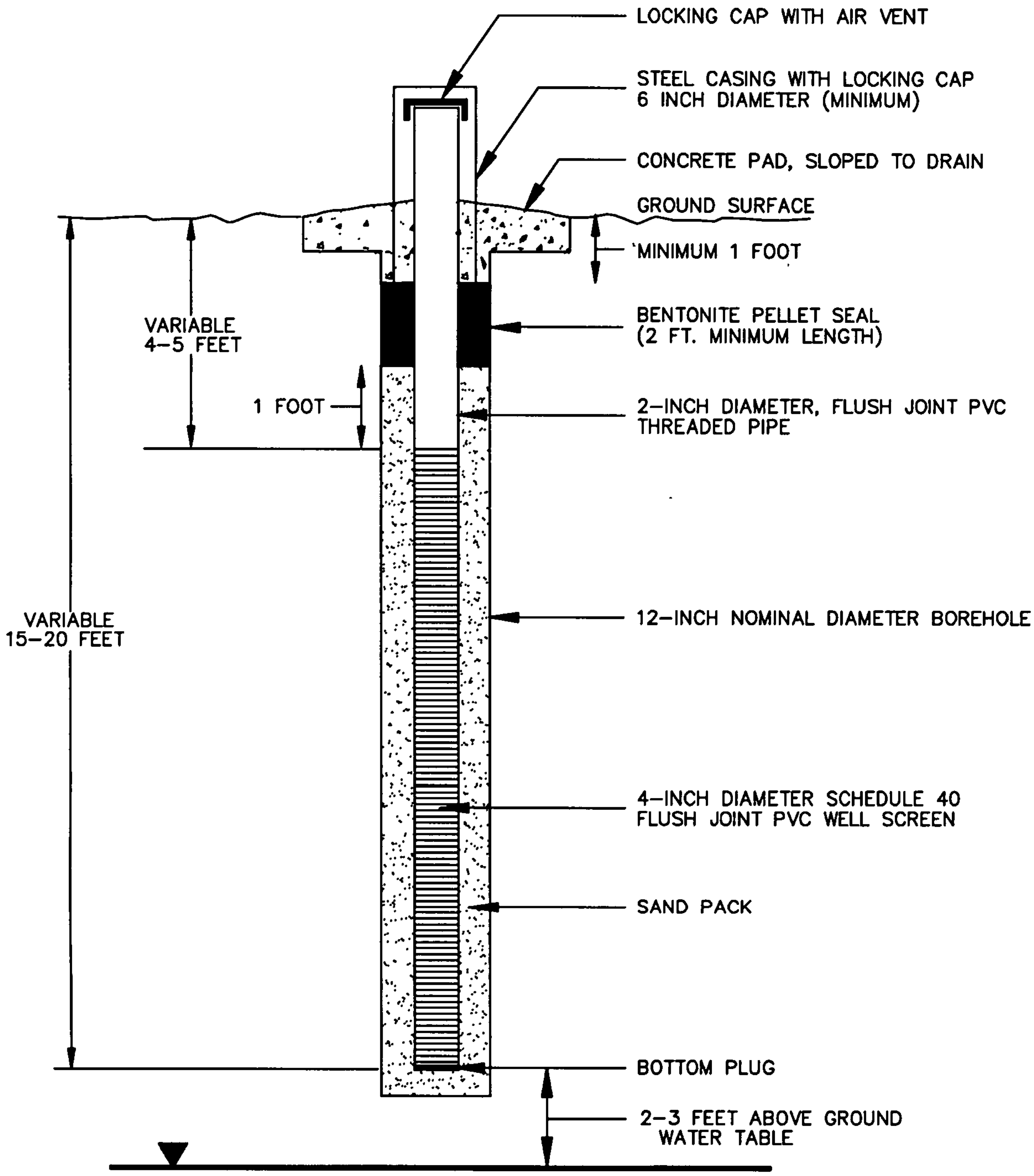

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FIGURE A–1.

TYPICAL SOIL VAPOR EXTRACTION WELL

Date: 8/93	Drawing No. 14282–Q101

14282SVW

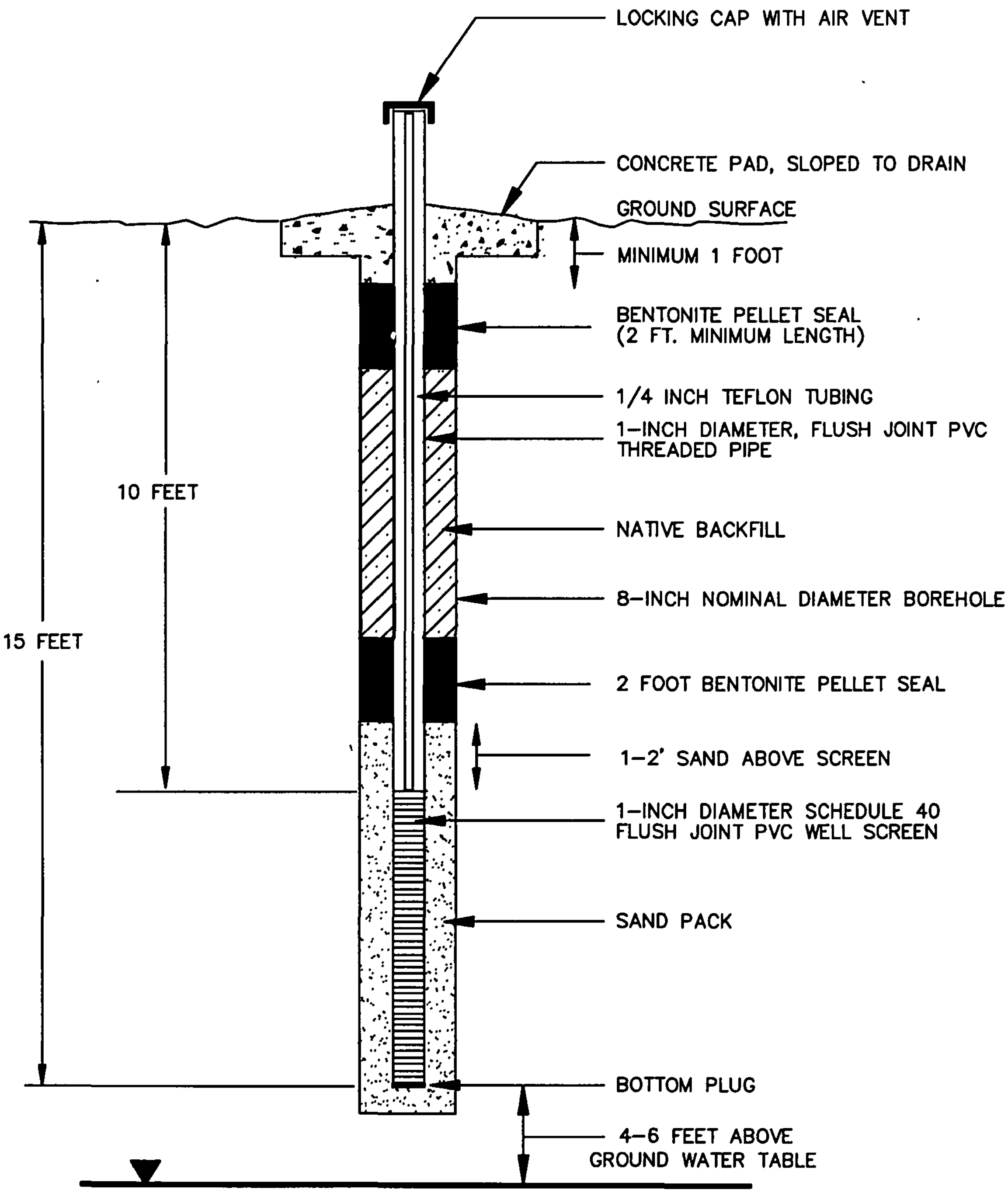

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FIGURE A-2.

TYPICAL SOIL VAPOR PROBE

Date: 8/93 | Drawing No. 14282-Q101

142825VP

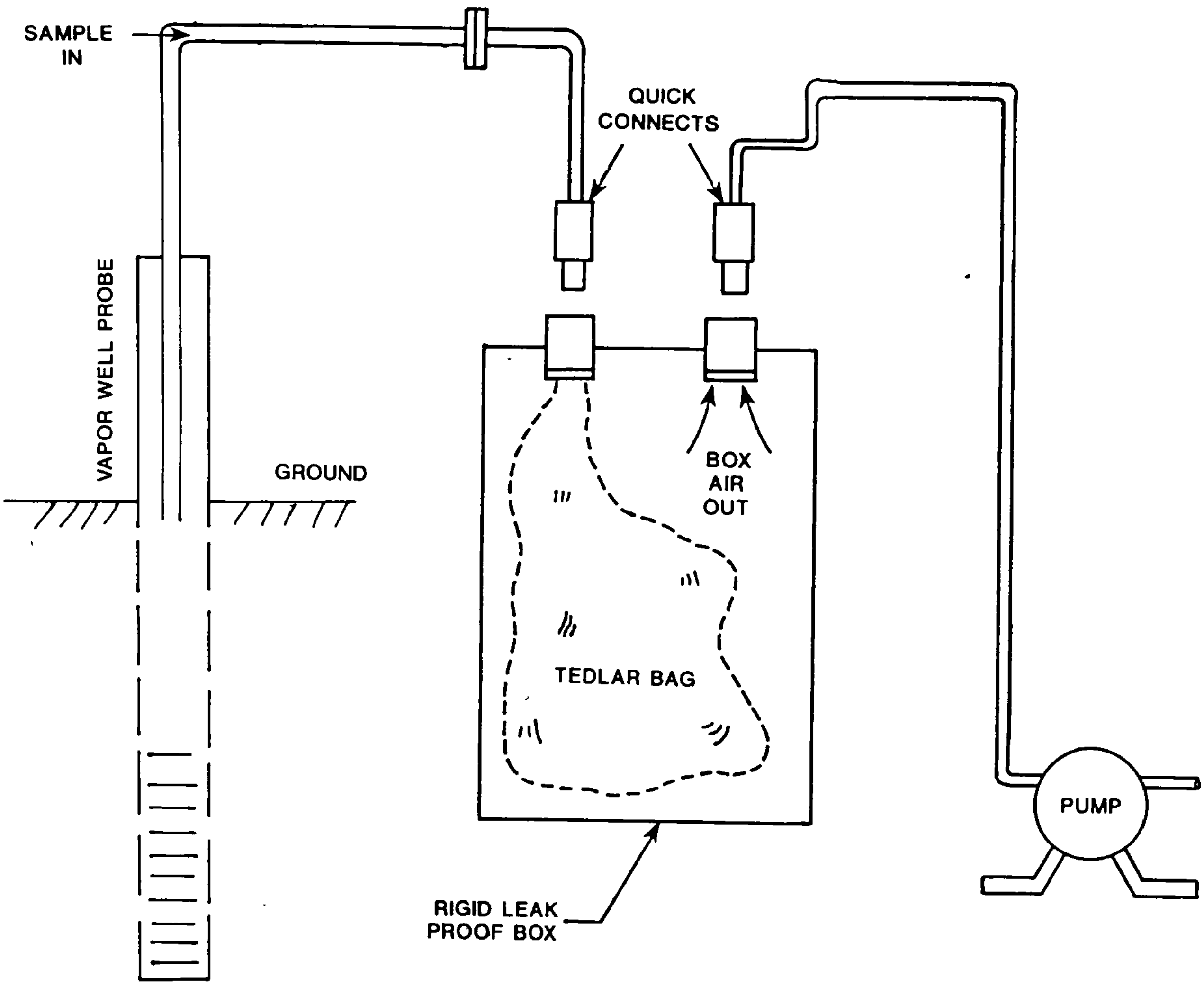

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FIGURE A-3.

INTEGRATED BAG SAMPLING TRAIN

Date: 8/93

Drawing No. 14282-Q101

APPENDIX B

INVESTIGATION-DERIVED WASTE PLAN

APPENDIX B
INVESTIGATION-DERIVED WASTE PLAN

1.0 WASTE MANAGEMENT

Investigation-derived waste (IDW) material includes material generated as a result of site investigation activities. These materials include auger cuttings, ground water development and sampling purge water, decontamination fluids, and expendable personnel protective equipment. During the course of the pre-design field exploration activities, care will be taken to minimize the amount of IDW material which is generated and handled.

Generally, IDW materials will be placed in DOT-approved 55-gallon drums. Drums will be filled to no more than 90 percent of capacity to allow for the potential expansion of waste material. Drums will be marked with labels and indelible liquid chalk pens by field investigation personnel. Drum labels will be of a contrasting color (e.g., yellow) relative to the drums (e.g., black). Information recorded on the drums and labels will include:

- generator (US Navy, Naval Education Training Center, Newport, Rhode Island, 02841)
- generator EPA identification number,
- source (e.g., site, well number),
- date(s) of generation,
- matrix (e.g., soil, water, etc.), and
- notes (e.g., odors, non-aqueous phase liquids, etc.)

The handling of specific IDW materials is described below. The handling and disposal of all IDW materials will be the responsibility of the US Navy with assistance provided by TRC. RIDEM and EPA - Region I will be consulted regarding the final disposition of all IDW material.

1.1 SOILS

Solid material derived from the subsurface exploration program (e.g., auger spoils, split spoon samples, etc.) will be continuously observed for evidence of potential contamination (e.g., discoloration, odors, etc.) and monitored for the presence of VOCs using a photo and/or flame ionization detector (PID or FID).

Drill cuttings produced from test borings which will not be used for the installation of vapor extraction wells or vapor probes will be backfilled into their respective borings and a cement-bentonite grout will be placed in the top one foot of the borehole as described in Appendix C. Excess drill cuttings produced from vapor extraction and test probes will be containerized in 55-gallon drums.

Drummed well boring cuttings will be segregated on pallets and staged on-site at the completion of the drilling activities. The Navy will be responsible for staging all drums. Prior to final disposition of these materials, the drums will be sampled and appropriately characterized to determine the applicable disposal requirements.

If the analytical results indicate the absence of contamination, the associated drummed soil will be returned to the ground surface near the respective source location. IDW material will not be placed closer than ten feet, nor further than twenty feet from its source location. The location(s) where any drill cuttings are placed will be recorded in a field notebook. EPA - Region I and RIDEM will be consulted prior to redepositing any IDW materials at the site.

If characterization of the drums' contents indicates the drill cuttings are hazardous, the drummed IDW materials will be transported by a licensed waste hauler for treatment or disposal in accordance with applicable state and federal regulations established under the Resource Conservation and Recovery Act (RCRA).

1.2 DECONTAMINATION SOLUTIONS

Downhole drilling equipment (e.g., augers, rods, cutting heads) will be steam cleaned prior to each use. Steam cleaning will be conducted in a designated heavy equipment decontamination area. Rinse waters from steam cleaning will be recovered and contained within drums for characterization and appropriate off-site treatment. Sediment/soil generated from steam cleaning operations will be drummed separately for appropriate characterization and proper disposal.

It is not anticipated that significant quantities of decontamination chemicals will be generated on-site during these investigations since the majority of the sampling equipment will be laboratory-decontaminated. However, decontamination chemicals used on-site (e.g., hexane, methanol, nitric acid) and water (distilled and tap) for the decontamination of sampling equipment (e.g., split spoons) will be separately collected, containerized, and labelled for proper treatment or disposal.

1.3 EXPENDABLE EQUIPMENT

Generation of expendable equipment (e.g., tyvek coveralls, gloves, boot covers, etc.) should be minimal based on the anticipated level of personnel protection (Level D) required during these investigations. Any expendable equipment generated as a result of field investigations will be placed into trash bags and disposed of in Newport Naval Base outdoor refuse containers. Refuse containers to be used for such disposal will be designated by the NETC Public Works Department. Expendable equipment which is known or believed to be contaminated (e.g., oily gloves) will not be disposed of in refuse containers. Such equipment, if any, will be drummed, labelled, and segregated for future disposal.

APPENDIX C

HYPERVENTILATE MODEL INFORMATION

United States
Environmental Protection
Agency

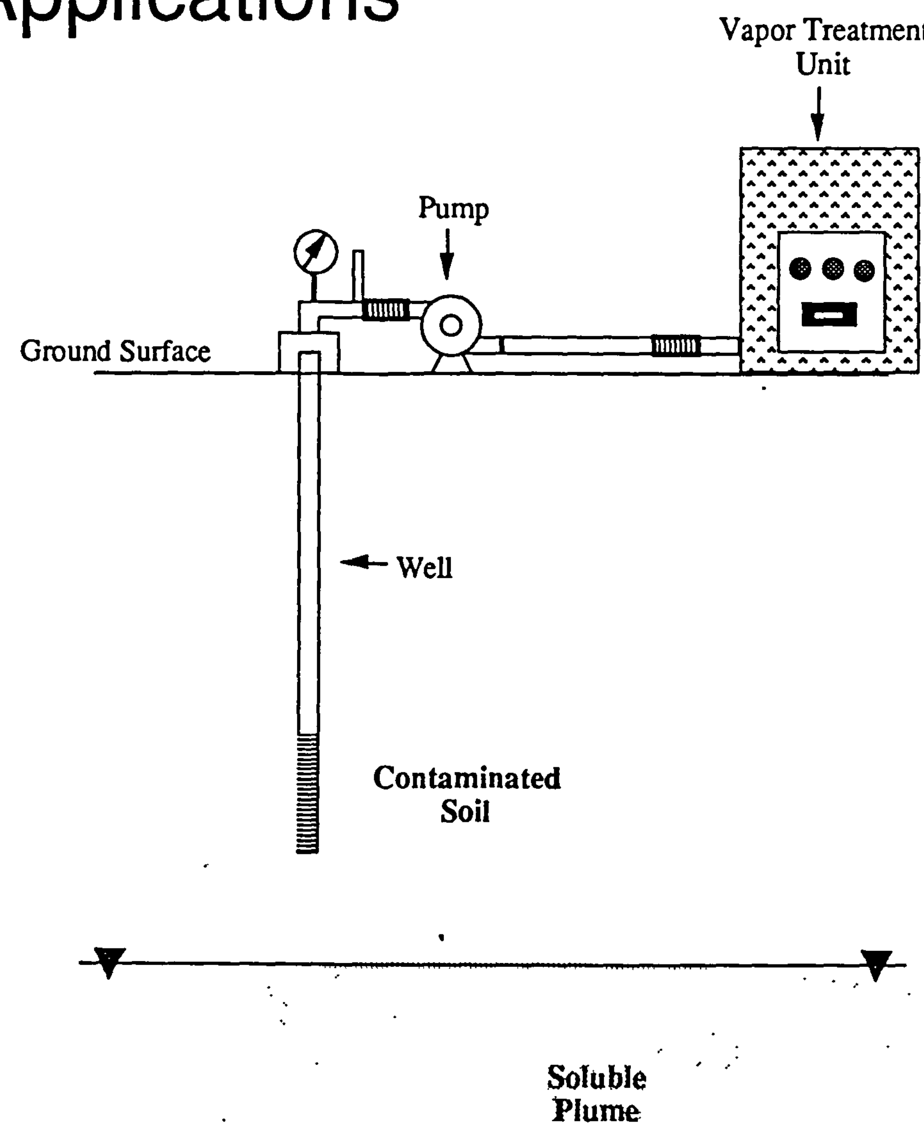
Solid Waste And
Emergency Response
(OS-420) WF

EPA 510-R-93-001
January 1993

EPA

HyperVentilate Users Manual (v1.01 and v2.0)

A Software Guidance System Created For Vapor Extraction Applications



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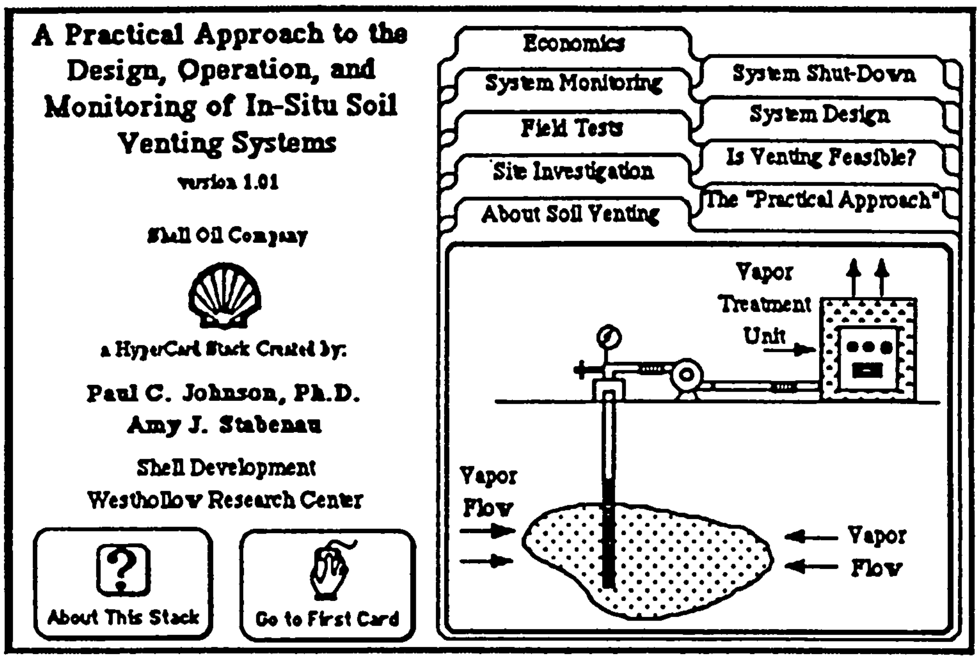
HyperVentilate
Users Manual

A Software Guidance System Created for Vapor Extraction Applications



by

Paul C. Johnson, Ph.D.

Shell Development
Westhollow Research Center
Environmental R&D
P. O. Box 1380
Houston, TX 77251

Apple® Macintosh™ HyperCard™
compatible version 1.01

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Addendum for Microsoft Windows/Spinnaker PLUS Version 2.0

Summary

HyperVentilate - the software guidance system created for vapor extraction applications is now available for IBM-compatible computers. In general, this new version (v2.0) appears and functions like the original Apple Macintosh HyperCard version. Due to differences in the computer platform and operating environment, however, there are some minor modifications. This addendum to the original users manual identifies those modifications.

HyperVentilate v2.0 is a product of collaboration between Shell Oil Company and U.S. EPA, and is still under evaluation. Should you encounter problems that you think are "bugs", please write to the author identifying the problem.

Modifications

- *software platform*
  The original Hyperventilate program was developed and operated under the Apple Macintosh HyperCard software environment, and initially there were no plans to develop an IBM-compatible version. Due to popular demand; however, the author relented and used the least painful method of adaption to the new platform. This was accomplished through the use of Spinnaker PLUS, a HyperCard-like program that can utilize pre-v2.0 HyperCard stacks and functions on both Macintosh and IBM-compatible platforms. The Microsoft Windows/Spinnaker PLUS version requires the user to have both Microsoft Windows and a "run-time" version of Spinnaker PLUS (Windows 3.0 version). Information on Spinnaker PLUS can be obtained from:

  Spinnaker Software   Jeff Boehm   Ext. 329
  201 Broadway $105.
  Cambridge, MA 02139
  (617) 494-1200

- *stack names*
  As listed on p4, of the original users manual, HyperVentilate for the Apple Macintosh consists of eight files. The Spinnaker PLUS version contains only seven files. The names are:

HyperCard Version Name	Spinnaker PLUS Version Name
Soil Venting Stack	SVS. sta
Soil Venting Help Stack	SVHS.sta
System Design	SD.sta
Air Permeability Test	APT.sta
Aquifer Characterization	AQ.sta
Compound List Update	CLU.sta
HypeVent	HYPEVENT.exe
f77.rl	none

- *installation*
  all files **must** be copied into the PLUS directory on your hard disk.

- *starting HyperVentilate v2.0b*
  To start HyperVentilate v2.0b, open the Windows "File Manager", navigate to within the PLUS directory, then open (double-click on) the file SVS.sta.

- *printing cards*
  You may experience difficulties with some of the "Print" buttons in the program. Read your PLUS manual to overcome these difficulties.

- *appearance of cards*
  Generally, the cards appear as they are printed in the manual. Due to platform differences, however, some text will appear different. This problem is unavoidable with Windows-based systems, as different users will have their computers configured with different screen fonts.

- *tab keys*
  Some cards utilize spreadsheets. In the HyperCard version the "tab" key is used to navigate through these tables. In the PLUS version the "tab" key is not active and you must use the "arrow" keys.

- *speed*
  Due to platform differences, the PLUS version does not operate as smoothly, or quickly, as the HyperCard version. The user will notice that with time the execution speed of the program will slow; therefore, it is recommended that you periodically exit from Windows and restart the system.

  On some machines, when HyperVentilate accesses the external compiled code HYPEVENT.EXE after clicking on the "Generate Predictions" button on card 16 of the SVS.sta stack, there will be a long pause (as long as a few minutes) as PLUS Windows, and HYPERVENT.EXE fight over available memory. Typically card 17 will eventually be displayed with a shaded rectangle along a portion of its lower base while this battle is occurring. Be patient and wait for the screen to blank out and display the message "HANG ON..." indicating that HYPEVENT.EXE is running. If you have limited memory (<4MG), or too many applications open, this message will not be displayed, and you will be returned to card 17 as if the program had run. The user needs to be aware that this may occur.

Software Installation Procedure

A discussion on how to load both Spinnaker PLUS and HyperVentilate

- Loading Spinnaker PLUS
- Creating the Spinnaker PLUS Icon and Opening Spinnaker PLUS
- Loading HyperVentilate
- Installing Spinnaker PLUS "Run-Time" Version with HyperVentilate

These directions presume that the user has a working knowledge of Microsoft Windows. The operation of Spinnaker PLUS, and therefore the IBM-compatible version of HyperVentilate requires Microsoft Windows Version 3.0 or higher. If you are using a version of HyperVentilate with a "run time" version of Spinnaker PLUS, skip to the "Loading HyperVentilate" instructions.

Loading Spinnaker PLUS

The Spinnaker PLUS package contains three 3.5-inch and three 5.25-inch diskettes from which to install the program. Use these steps to install the program:

1. Enter Windows.
2. Double-click on the "Main" window icon (if this window is not already open).
3. Double-click on the "File Manager" icon; this will display the "Directory Tree" window.
4. Insert Disk 1 into the appropriate drive (A or B).
5. In the upper left corner of the "Directory Tree" window you will see symbols representing the drives on your system. Click on the drive (A or B) where you just inserted Disk 1.
6. A listing of the files on Disk 1 will appear; double click on the file "plssetup.exe".
7. A window called "Spinnaker PLUS Setup" will appear. Change the path of the installation from "C:\PLUS" to "C:\WINDOWS\PLUS" (Note: "C" is a standard drive specification; you should use the letter that designates where Windows is installed on your system). Click on "Continue." The program will start copying files from Disk 1. Follow the rest of the instructions and prompts on the screen.
8. When the installation has been completed, exit the "File Manager" and exit Windows.

Creating the Spinnaker PLUS Icon and Opening Spinnaker PLUS

1. Re-enter Windows. (Note: exiting and re-entering Windows is a step recommended by the manufacturer of Spinnaker PLUS).

2. Close all windows so that the "Program Manager" window is the only one displayed on your screen.

3. At the bottom of the window, there will be program icons displayed for "Main," "Accessories," and others. Is there a program icon named "Windows Applications?" If yes, double-click on it and go to Step 4. If no, continue with Steps 3a-c to create one.

3a. Click on "File" and drag down to "New." A window called "New Program Object" will appear.

3b. Check to make sure "Program Group" is selected; click on "OK." A window called "Program Group Properties" will appear.

3c. The cursor will be located at the description field. Type in the words "Windows Applications" and click on "OK." An empty window will appear called "Windows Applications."

4. With this window open, click on "File" and drag down to "New." A window called "New Program Object" will appear.

5. Check to make sure "Program Item" is selected; click on "OK." A window called "Program Item Properties" will appear.

6. Click on "Browse." A window called "Browse" will appear.

7. Under "Directories," double-click on "plus."

8. Under "File Name," double-click on the "plus.exe" file. This will bring you back to the "Program Item Properties" window.

9. Click on "Change Icon," click on the icon for "Plus," and click on "OK."

10. You will now be back at the "Program Item Properties" window. Click on "OK."

11. You will now be back to the "Windows Applications" window displaying your "Plus" icon.

12. Double-click on the "Plus" icon to run Spinnaker PLUS.

Loading HyperVentilate

The HyperVentilate package contains one 3.5-inch diskette from which to install the program. The program can be installed from either the DOS prompt or from within Windows. The following procedures are used for both types of installations (Note: For these installation procedures, the 3.5-inch drive from which you will be installing the program is assumed to be the B drive).

DOS Installation

1. Insert the HyperVentilate disk into the appropriate drive.

2. From the C:\> prompt in DOS, type "COPY B:*.* C:\WINDOWS\PLUS".

Windows Installation

1. Follows Steps 1-5 of the "Loading Spinnaker Plus."

2. Click on the B:\ folder icon so that it is highlighted and/or a dotted line appears around it.

3. Click on "File" and drag down to the "Copy" command. The "Copy" window will appear.

4. The curser will be located at the "To" path. Type in "C:\WINDOWS\PLUS"; click on "OK."

5. When the installation is complete, exit from the "File Manager."

Opening HyperVentilate

1. Enter Windows.

2. Double-click on the "Windows Applications" icon (if this window is not already open).

3. Double-click on the "Plus" icon.

4. Close the "Home" window.

5. Click on "File" and drag down to "Open." The window "Open Stack" will appear.

6. Either double-click on the "SVS.STA" file or click on "SVS.STA" and then click on "Open." The user is now in HyperVentilate.

Installing Spinnaker PLUS "Run-Time" Version with HyperVentilate

1. Create a subdirectory on the hard disk for HyperVentilate and Spinnaker PLUS "Run Time." For example, from the C:\> prompt, type "MD WINDOWS\PLUS".

2. Copy all the files from both the Spinnaker PLUS "Run Time" diskette and the HyperVentilate diskette to the subdirectory. For example, from the C:\> prompt, type "COPY B:*.* C:\WINDOWS\PLUS".

3. Follow directions in "Creating the Spinnaker PLUS Icon and Opening Spinnaker PLUS" with the following exception: substitute "plusrt.exe" for "plus.exe" in Step 8.

4. Follow directions for "Opening HyperVentilate" to run the program.

Disclaimer

The HyperVentilate software package was completed under a Federal Technology Transfer Act Cooperative Research and Development Agreement between EPA and Shell Oil Company, signed in 1990.

EPA is facilitating the distribution of HyperVentilate because the Agency has found the software and manual to be helpful tools, especially in teaching users about in situ soil venting and in guiding them through a structured thought process to evaluate the applicability of soil venting at a particular site. EPA's Office of Underground Storage Tanks advocates the use of innovative cleanup technologies, and in situ soil venting is recognized as an effective remediation alternative for many underground storage tank sites.

HyperVentilate is based on the document titled, "A Practical Approach to the Design, Operation, and Monitoring of Soil Venting Systems" by P. C. Johnson, C. C. Stanley, M. W. Kemblowski, J. D. Colthart, and D. L. Byers, published 1990 by Shell Oil Company. The program asks a series of questions and forms a "decision tree" in an attempt to identify the limitations of in situ soil venting for soils contaminated with gasoline, solvents or other relatively volatile compounds.

EPA and Shell Oil Company make no warranties, either express or implied, regarding the HyperVentilate computer software package, its merchantability, or its fitness for any particular purpose. EPA and Shell Oil Company do not warrant that this software will be error free or operate without interruption. EPA and Shell Oil Company do encourage testing of this product.

EPA will not provide installation services or technical support in connection with the HyperVentilate computer software package. Neither will EPA provide testing, updating or debugging services in connection with the enclosed computer software package.

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Comments/Suggestions?

Comments and/or suggestions about the usefulness of this program can be mailed to:

Paul C. Johnson
Shell Development
Westhollow Research Center
P.O. Box 1380
Room EC-649
Houston, TX 77251-1380

Please do not call the author and/or Shell with questions about the use or interpretation of results from this program.

Table of Contents

I. *Introduction*

In situ vapor extraction, or soil venting is recognized as an attractive remediation alternative for "permeable" soils contaminated with "volatile" compounds. As Figure 1 illustrates, vapors are removed from extraction wells, thereby creating a vacuum and vapor flow through the subsurface. Until the residual contamination is depleted, contaminants will volatilize and be swept by the vapor flow to extraction wells. While its use has been demonstrated at service stations, Superfund sites, and manufacturing locations (see Hutzler et al. [1988] for case study reviews), vapor extraction systems are currently designed more by intuition than logic. In fact, many systems are installed at sites where the technology is not appropriate.

"A Practical Approach to the Design, Operation, and Monitoring of In Situ Soil Venting Systems" [Johnson et al. 1990a - see Appendix G] is a first attempt at creating a logical thought process for soil venting applications. The article, which is based on earlier results of Thornton and Wootan [1982], Marley and Hoag [1984], Johnson et al. [1990], and discussions with several of these authors, describes a series of calculations for determining: (a) if soil venting is appropriate at a given site, (b) limitations of soil venting, and (c) system design parameters, such as minimum number of extraction wells and potential operating conditions.

HyperVentilate is a software guidance system based on the Johnson et al. [1990a] article. The software performs all necessary calculations and contains "help cards" that define the equations used, perform unit conversions, and provide supplementary information on related topics. In addition, a 62-compound updatable chemical library (to a maximum of 400 compounds) is included.

Initial development of this program occured under the Apple Macintosh HyperCard environment, due to its programming simplicity, ability to incorporate text and graphics, and interfacing with other Macintosh programs (such as FORTRAN codes, etc.). The objective was to create a user-friendly software package that could be both educational for the novice environmental professional, and a functional tool for more experienced users. The OASIS [1990] system created at Rice University for groundwater contamination problems is another excellent example of the use of HyperCard as a technology transfer tool.

This document is a users manual for **HyperVentilate**. It contains sections describing the installation and operation of the software. During the development of **HyperVentilate**, the goal was to create a guidance system that could be used with little or no instruction. Experienced Apple Macintosh users, therefore, can load and explore the capabilities of this program after glancing at the "*Loading HyperVentilate Software*" section. Those users that are less comfortable about exploring software without a manual are encouraged to read through it once, and work through the sample problem. It is intentionally brief, and a beginner should be able to navigate through the system in less than a couple hours. It is assumed that the user has some previous Macintosh experience. If not, consult a Macintosh users manual for a quick tutorial.

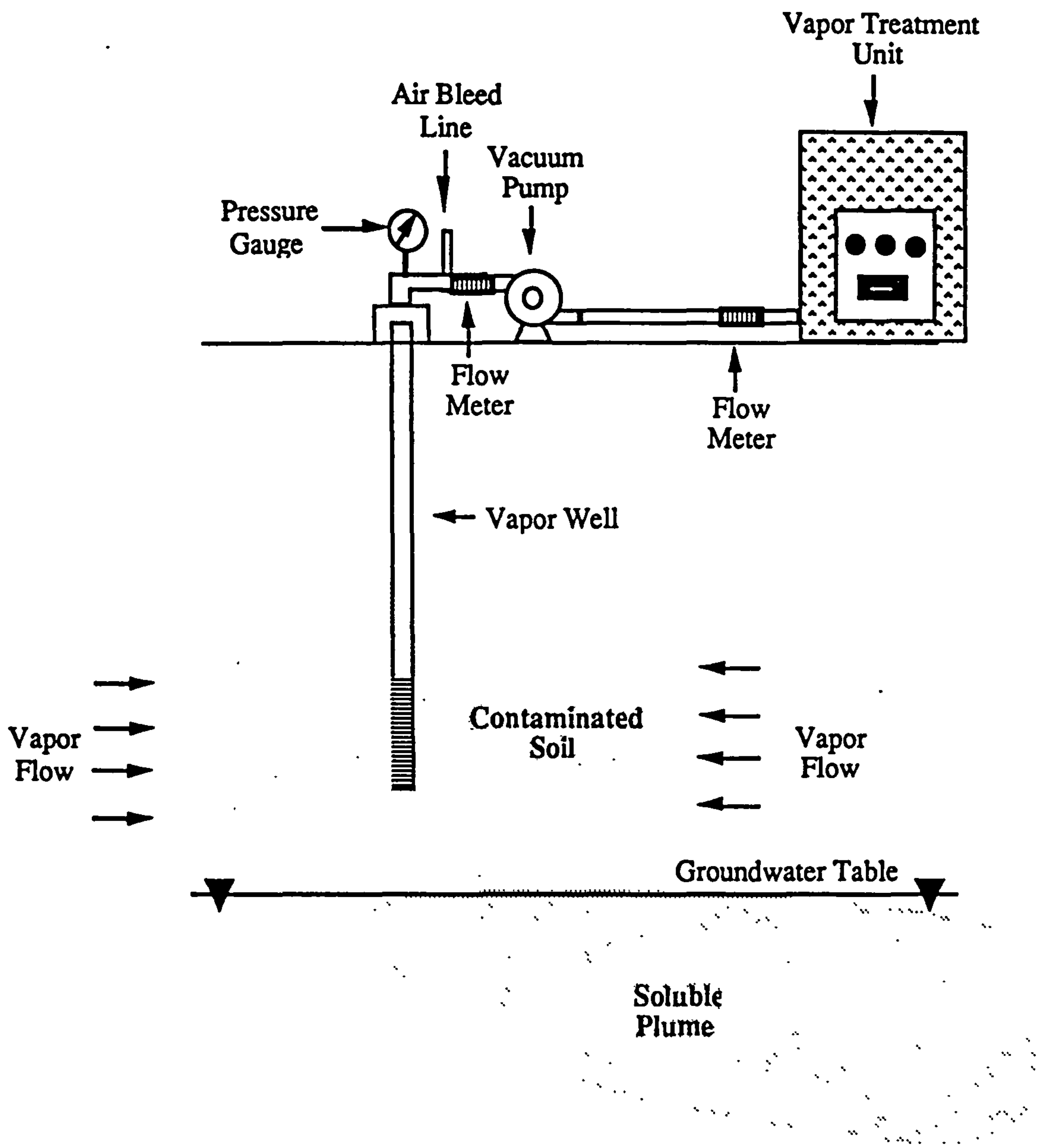


Figure 1. Schematic of a typical vapor extraction operation.

II. *Definition of Some Terms Appearing in this Manual*

button	- an object on a "card" that causes some action to be performed when "clicked" on
card	- an individual screen that you view on your monitor
click	- refers to the pressing and releasing of the button on your mouse
drag	- refers to holding down the mouse button while moving the mouse
field	- a text entry location on a "card"
HyperCard	- a programming environment created by Apple Computer, Inc.
mouse	- the device used to move the cursor within your monitor
select	- refers to "dragging" the cursor across a "field"
stack	- a group, or file, of "cards"

III. *Software/Hardware Requirements*

Apple Macintosh **HyperVentilate** version 1.01 requires an Apple Macintosh (or equivalent) computer equipped with at least 1 MB RAM (2 MB preferable), a hard disk, and the Apple HyperCard Software Program (v 2.0). Check to make sure that your system software is compatible with your version of HyperCard.

IV. *Loading HyperVentilate Software*

HyperVentilate is supplied on an 800 kB double-sided, double density 3.5" diskette. Follow the instructions listed below to insure proper operation of the software.

1) Insert the **HyperVentilate** disk into your computer's floppy drive. The **HyperVentilate** disk should contain the files:

   - "Soil Venting Stack"
   - "Soil Venting Help Stack"
   - "System Design"
   - "Air Permeability Test"
   - "Aquifer Characterization"
   - "Compound List Update"
   - "HypeVent"
   - "f77.rl"

2) Copy these files onto your hard disk. **They must be copied into the folder that contains the "HyperCard" program, or else the software will not operate properly.**

3) Eject the **HyperVentilate** disk

V. *Using HyperVentilate*

The authors of **HyperVentilate** intend it to be an application that requires little pre-training for the user. It is mouse-driven and instructions are included on each card, so please take the time to read them when you first use **HyperVentilate.**

This section of the users manual is divided into three subsections. Start-up instructions are given in the first, basic features of the cards are described in the second, and a sample exercise is presented in the third. For reference, copies of all cards, as well as more details on each are given in Appendices A through F.

V.1. Starting HyperVentilate

1) Those users with color monitors should use the "Control Panel" (pull down the "" menu and select "Control Panel", then click on the "Monitors" icon) to set their monitors to black and white, and two shades of grey.

2) To avoid unnecessary "card-flipping", set the "Text Arrows" option in your "Home" stack "User Preferences" card to on. You can get to this card from within any HyperCard application by selecting "Home" under the "Go" menu. This will take you to the first card in the "Home" stack. At this point click on the left-pointing arrow and the "User Preferences" card will appear on your screen. Then click on the square to the left of "Text Arrows" until an "X" appears in the square.

3) **HyperVentilate** is started by double-clicking on the "Soil Venting Stack" file icon from the Finder (or Desktop), or by choosing "Open" under the "File" menu (*Note that using a more advanced version of HyperCard than the one under which this system was developed (v 2.0) may require you to first "convert" each of the seven HyperCard stacks contained in HyperVentilate*).

4) Your monitor should display the card shown in Figure 2. Note that there are a number of buttons on this card; there are two at the lower left corner, and then each file folder tab is also a button (some cards may contain less obvious "hidden" buttons; try clicking on the authors name on the title card for example). Clicking on any of these will take you to another card. For example, clicking on the "About This Stack" button will take you to the card shown in Figure 3, which gives a brief description about the use of buttons and fields. Read this card well.

5) Explore for a few minutes. Try to see where various buttons will take you, try entering numbers in fields, or play with calculations. Again, just remember to read instructions given on the cards.

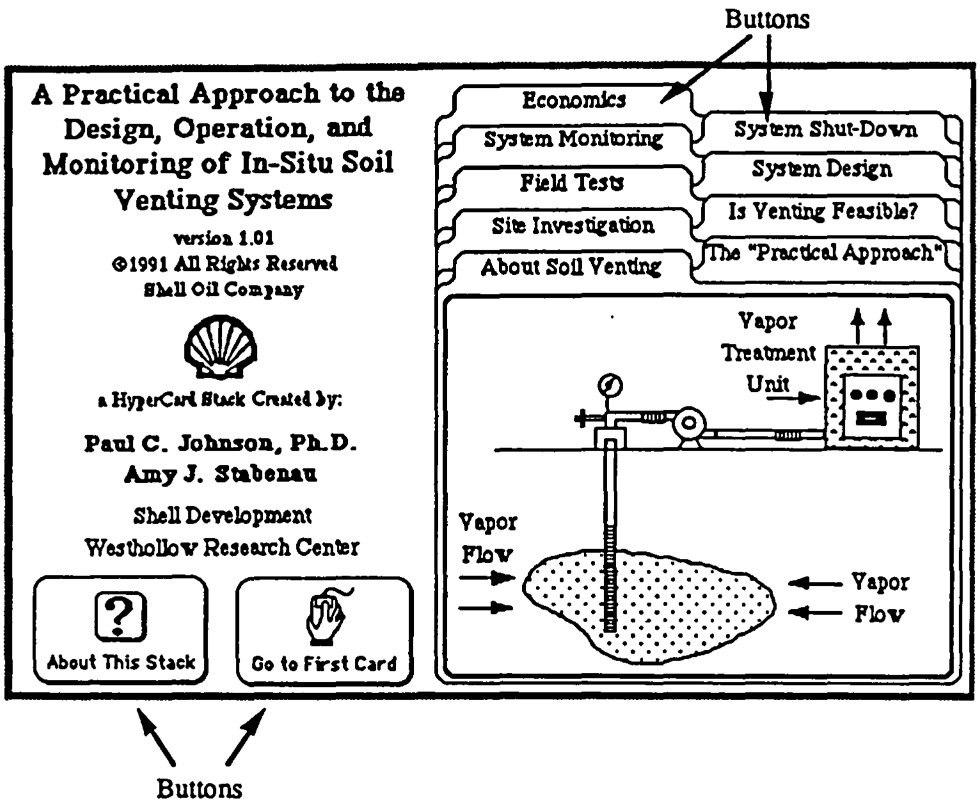


Figure 2. First Card of the "Soil Venting Stack" stack.

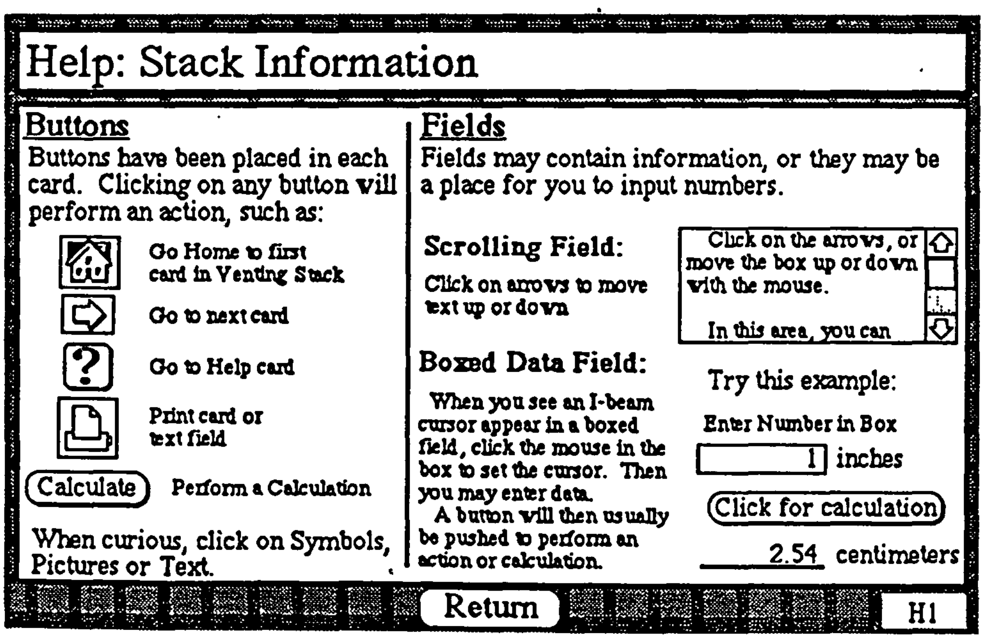


Figure 3. Card H1 of the "Soil Venting Help Stack" stack.

Step 3: Location: Card H1 of the "Soil Venting Help Stack" stack.
Action: Play with the buttons and scrolling field. Practice entering a number in the field in front of "inches". Place the cursor in the box. It will change from a hand to an "I-bar" as it enters the field. Hold down the mouse button and drag the I-bar across the entry, which will become hilited. Now type in another number, or hit the delete key. Practice until you feel comfortable selecting text and entering numbers. Then click on the "Click for Calculation" button. When you are done practicing, click on the "Return" button.
Result: Return to the title card of the "Soil Venting Stack" (Figure 2).

Step 4: Location: Title Card of the "Soil Venting Stack" stack.
Action: Click on the "Economics" file folder tab.
Result: You are now at card 27 of the "Soil Venting Stack" stack. Take a quick glance at this card, which is displayed in Figure 6.

Step 5: Location: Card 27 of the "Soil Venting Stack" stack.
Action: Click on the "House" button in the lower left corner.
Result: You are back at the title card (Figure 2).

Step 6: Location: Title card of the "Soil Venting Stack" stack.
Action: Click on the "Go to First Card" button.
Result: You are now at card 1 of the "Soil Venting Stack" stack (Figure 7).

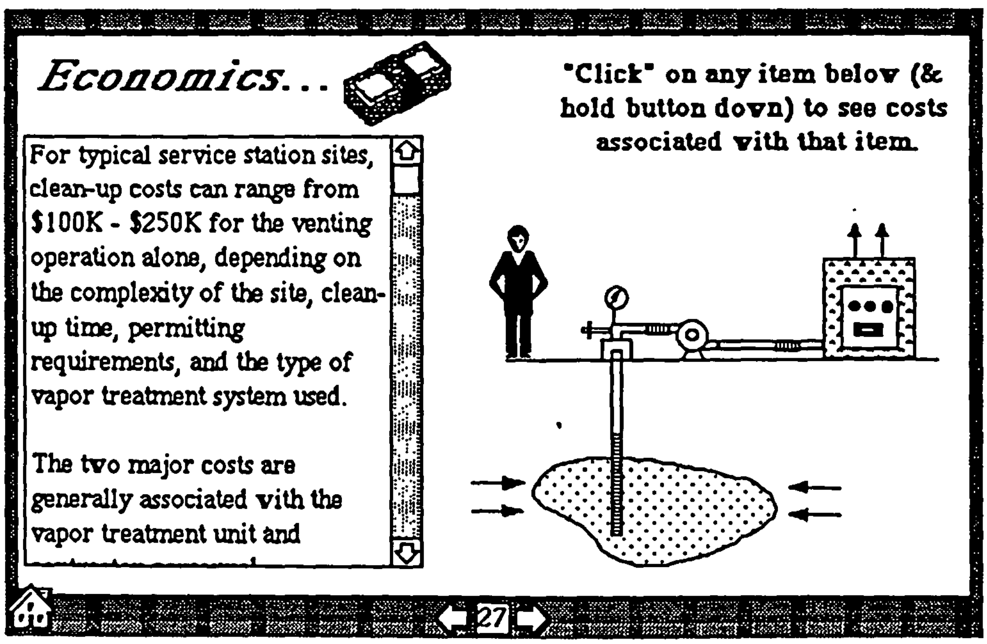


Figure 6. Card 27 of the "Soil Venting Stack" stack.

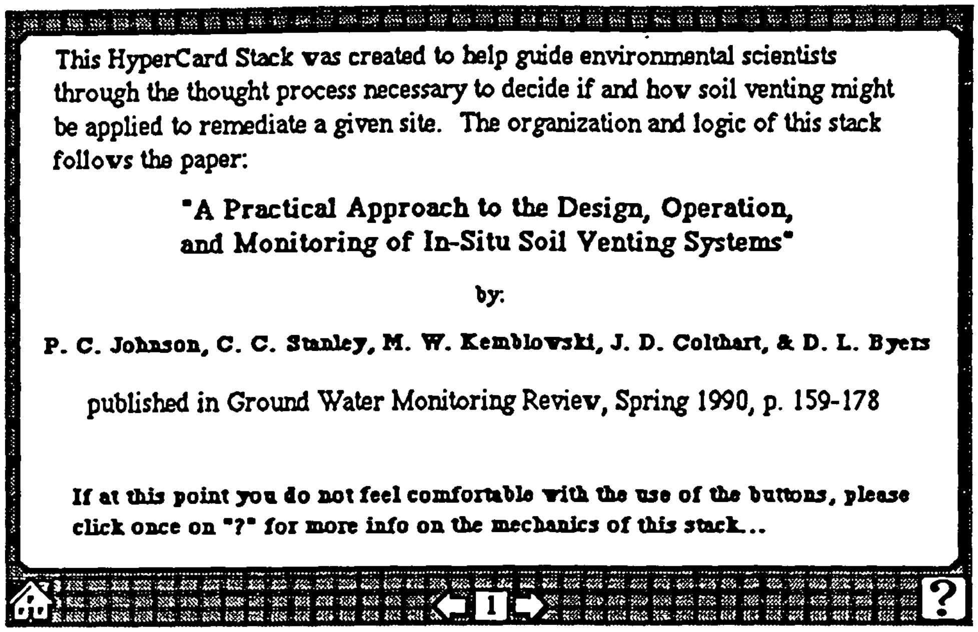


Figure 7. Card 1 of the "Soil Venting Stack" stack.

Step 7: Location: Card 1 of the "Soil Venting Stack" stack.
Action: Click on the right-pointing arrow.
Result: You are now at Card 2 of the "Soil Venting Stack" stack (Figure 8).

Step 8: Location: Card 2 of the "Soil Venting Stack" stack.
Action: Read the text, and click on the "down" and "up" arrows on the displayed text field under "***About Soil Venting...***" to make the field scroll. Then click on the left-pointing arrow at the card bottom.
Result: You are now back at card 1 of the "Soil Venting Stack" (Figure 7).

Step 9: Location: Card 1 of the "Soil Venting Stack" stack.
Action: Click on the right pointing arrow.
Result: You are again at card 2 of the "Soil Venting Stack" stack (Figure 8). By now you should feel comfortable using the left- and right-pointing arrows to travel through the stack.

Step 10: Location: Card 2 of the "Soil Venting Stack" stack.
Action: Click on the "?" button in the lower right corner of the card. This button indicates that there is a "Help" card containing additional information.
Result: You are now at card H2 of the "Soil Venting Help Stack" stack (Figure 9). Scroll through the list of references, then click on the "Return" button to return to card 2 of the "Soil Venting Stack" stack.

At this point you should feel comfortable navigating around in **HyperVentilate**.

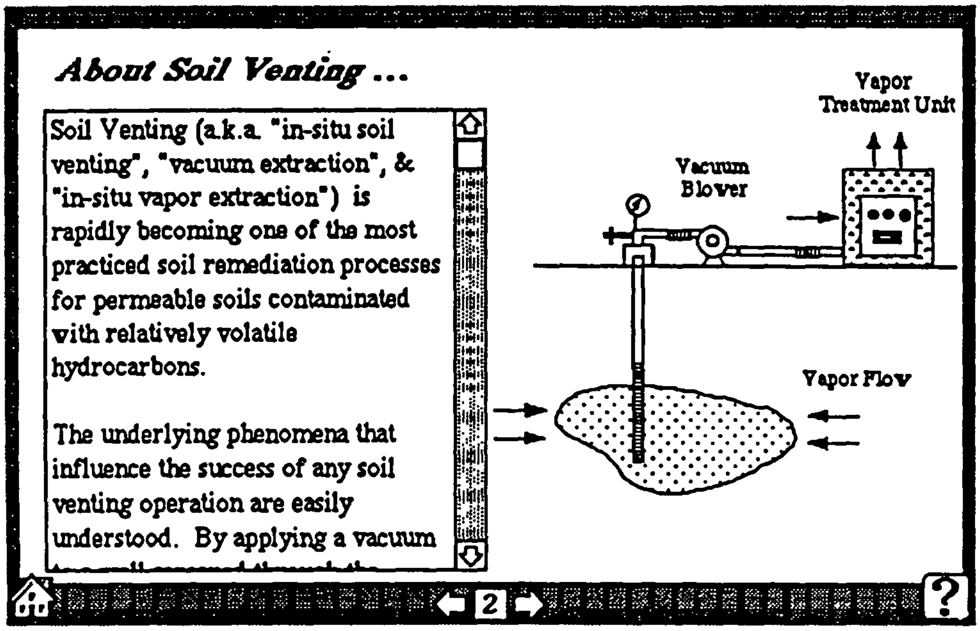


Figure 8. Card 2 of the "Soil Venting Stack" stack.

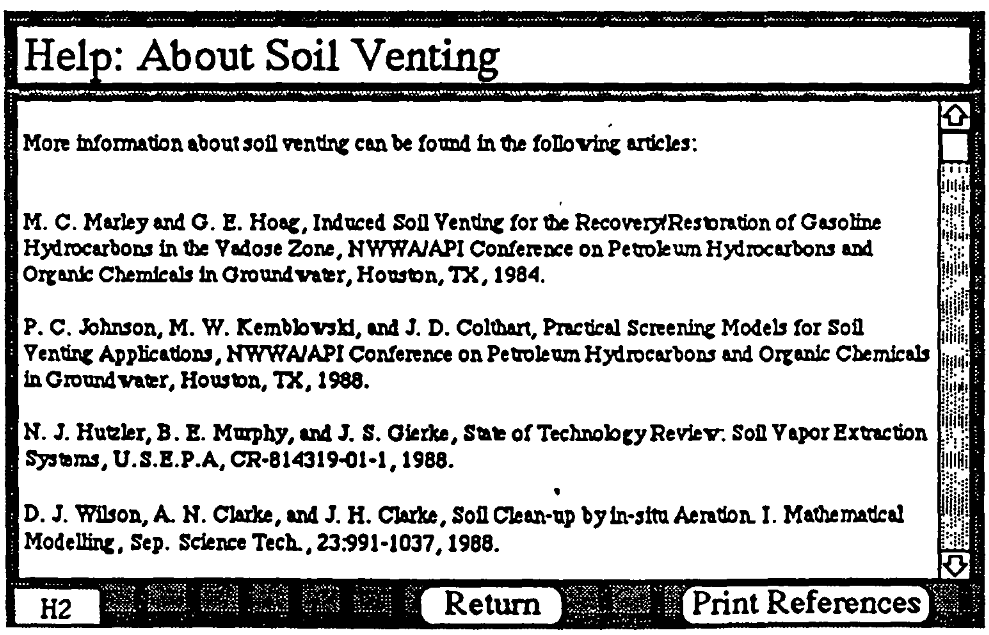
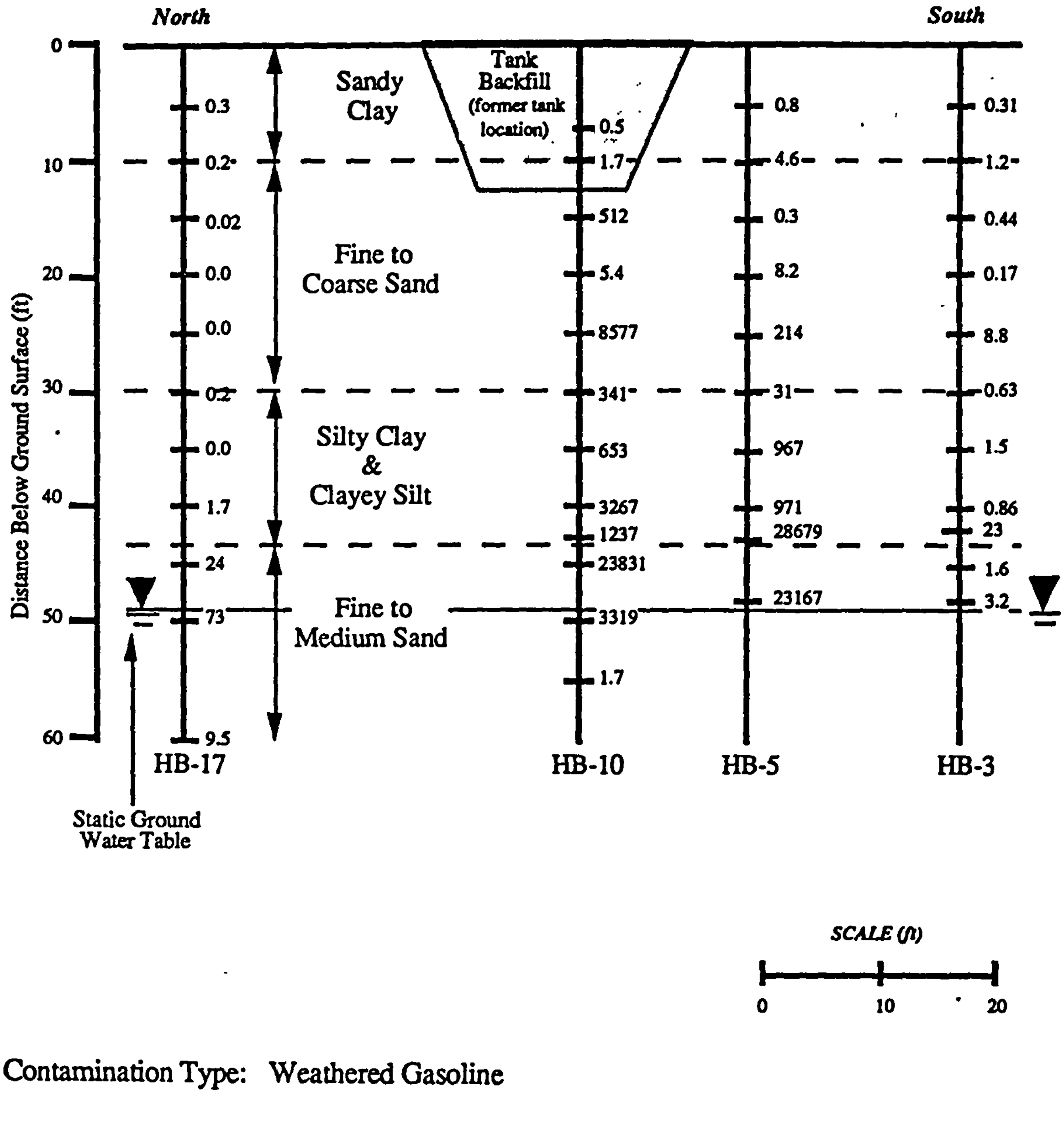


Figure 9. Card H2 of the "Soil Venting Help Stack" stack.

V.3.2 Sample Problem Exercise - Is Venting Appropriate?

In §V.3.2. you will work through an example problem to illustrate how one might decide if venting is appropriate at any given site. For the purpose of this example we will use the example site information given in Figure 10.



Contamination Type: Weathered Gasoline

Figure 10. Sample site data (Johnson et al. [1990a]). Total petroleum hydrocarbons (TPH) [mg/kg] values are noted for each boring.

Using your newly developed navigational skills and the right pointing arrow located at the bottom of each card, slowly step your way through the stack until you reach card 7 of the "Soil Venting Stack" stack (Figure 11). Take your time to read the text and "Help" cards associated with each card along the way.

Step 1: Location: Card 7 of the "Soil Venting Stack" stack.
Action: Read this card. It explains the process that you will use to decide if venting is appropriate. Then advance to card 8 of the "Soil Venting Stack" stack.
Result: You are now at card 8 of the "Soil Venting Help Stack" stack (Figure 12).

Step 2: Location: Card 8 of the "Soil Venting Help Stack" stack.
Action: Read the instructions on this card. Take the time to read the information on the two "Help" cards: "Info about Calculation" and "About Soils (& Unit Conversions)".

Now we will evaluate the efficacy of applying in situ soil venting to the lower soil zone (45 - 50 ft below ground surface) in Figure 10, which is composed of fine to medium sands. It also is the zone of highest hydrocarbon residual levels (>20000 mg/kg TPH in some areas).

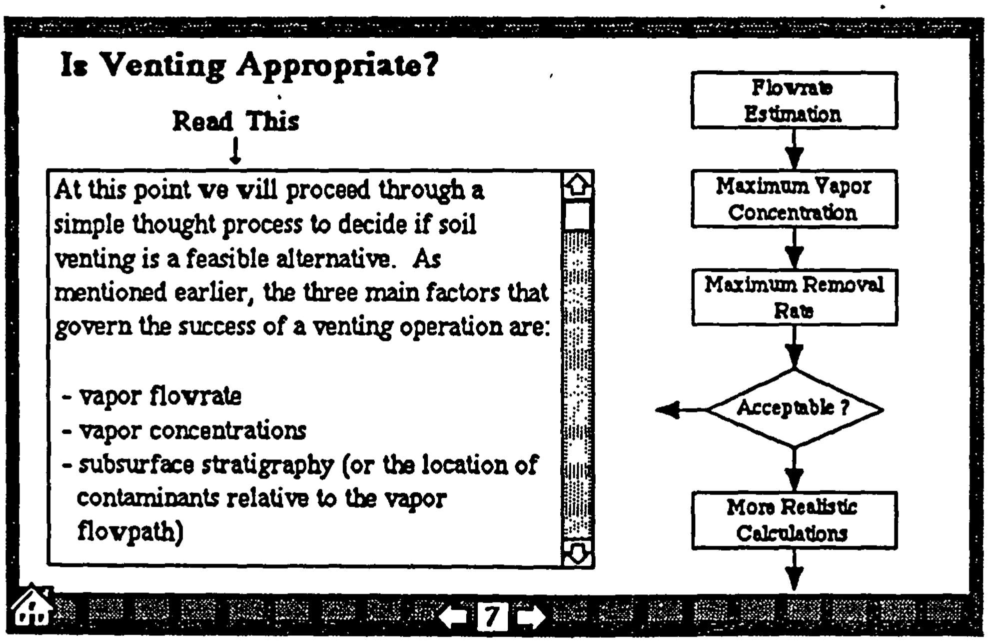


Figure 11. Card 7 of the "Soil Venting Stack" stack.

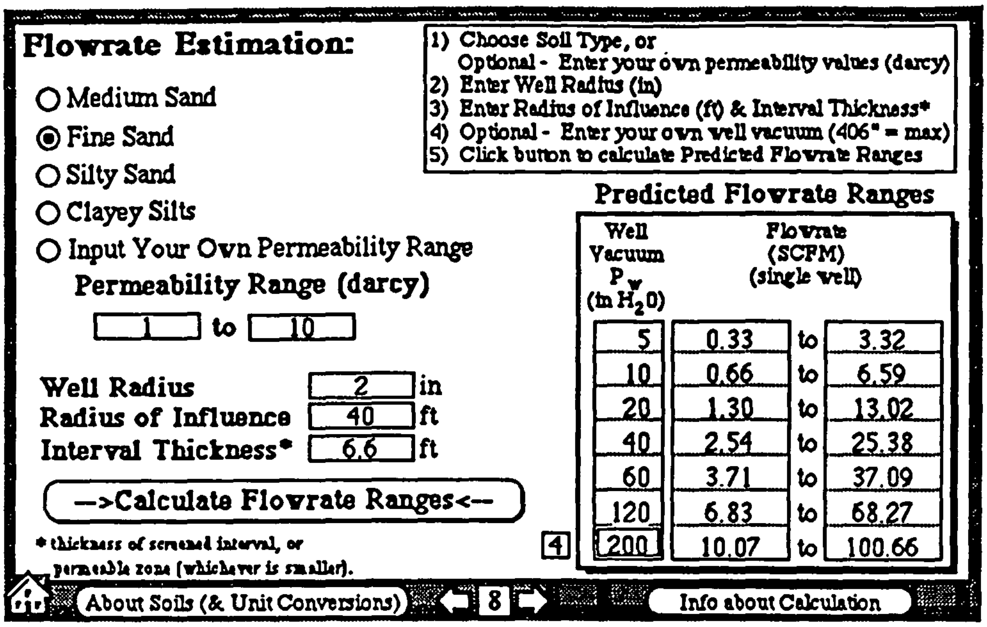


Figure 12. Card 8 of the "Soil Venting Stack" stack.

Step 3: Location: Card 8 of the "Soil Venting Stack" stack.
Action: Choose the "Fine Sand" soil type, and enter:

well radius =	2 in
radius of influence =	40 ft
interval thickness =	6.6 ft
user input vacuum =	200 in H_2O

into the appropriate fields, then click on the "-->Calculate Flowrate Ranges<--" button.
Result: The flowrate ranges are calculated and displayed. Your screen should now look like Figure 12. The calculated values are estimates of the flowrate to a single vertical well (and are only valid estimates when your conditions are consistent with the assumptions built into the calculation - see Johnson et al. [1990a, b] for more details).

Step 4: Location: Card 8 of the "Soil Venting Stack" stack.
Action: Click on the right pointing arrow to advance to card 9. Read the information on this card, then advance to card 10
Result: You are now at card 10 of the "Soil Venting Stack" stack (see Figure 13).

Step 5: Location: Card 10 of the "Soil Venting Stack" stack.
Action: Assume that the soil temperature at our sample site is 18° C. Enter this value in the appropriate field, then hit the "return" key. This action clears all values from the other fields.

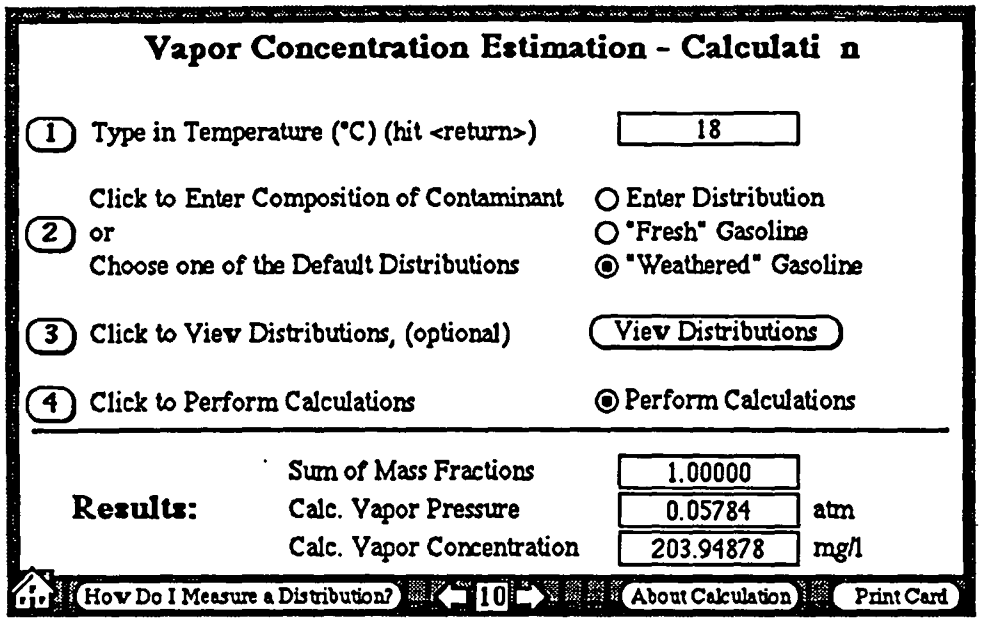


Figure 13. Card 10 of the "Soil Venting Stack" stack.

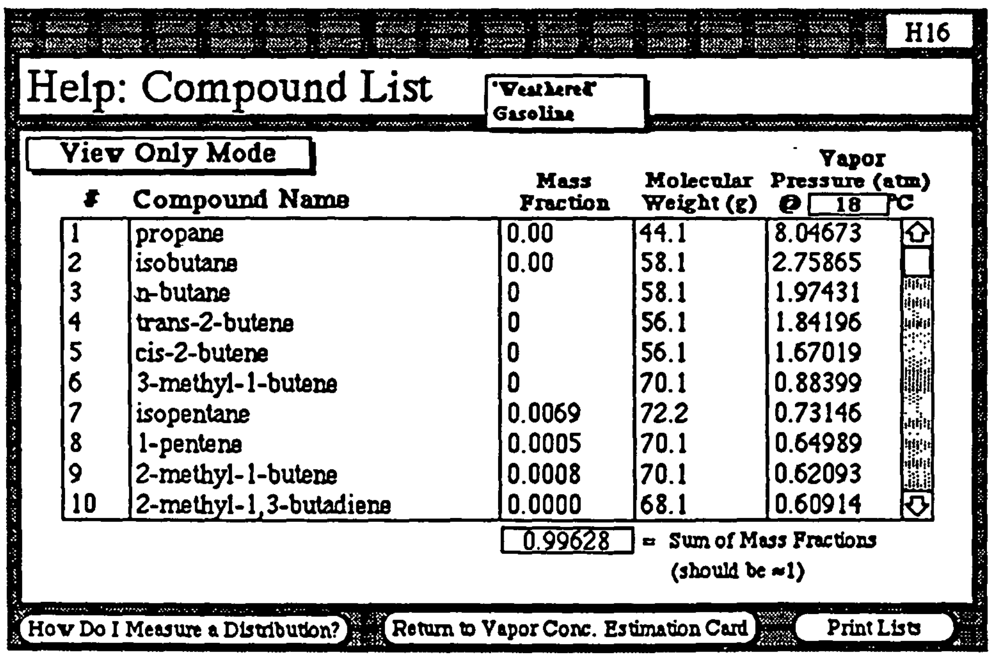


Figure 14. Card H16 of the "Soil Venting Help Stack" stack.

At this site the residual hydrocarbon is a "weathered" gasoline, so choose this selection from the three composition options listed. The "Fresh" and "Weathered" gasoline selections correspond to pre-programmed compositions that are useful for estimation purposes. If you knew the composition of your residual, then you could enter it by selecting the "Enter Distribution" option. Click on the "View Distributions" button to take a look at the compound library and the pre-specified composition of "weathered" gasoline.

Result: You are now at card H16 of the "Soil Venting Help Stack" stack (see Figure 14).

Step 6:

Location: Card H16 of the "Soil Venting Help Stack" stack.

Action: View the library and pre-specified composition. If you are interested, explore some of the help cards. Then click on the "Return to Vapor Conc. Estimation Card" button to return to card 10 of the "Soil Venting Stack" stack.

Result: You are now at card 10 of the "Soil Venting Stack" stack (Figure 13).

Step 7:

Location: Card 10 of the "Soil Venting Stack" stack.

Action: Click on the "Perform Calculations" button.

Result: **HyperVentilate** calculates the maximum possible vapor concentration corresponding to the specified composition and temperature. The results are displayed in Card 10 of the "Soil Venting Stack" stack, which should now look like Figure 13.

Step 8:

Location: Card 10 of the "Soil Venting Stack" stack.

Action: Using the right-pointing arrow button, advance to card 11 of the "Soil Venting Stack" stack. Take the time to read the text, then click on the "Calculate Estimates" button

Result: You are at card 12 of the "Soil Venting Stack" stack. The calculated flowrates and maximum possible removal rates are displayed along with an updated list of the input parameters that you have entered. Your screen should look like Figure 15, if you have chosen the "lb/d" units.

Step 9:

Location: Card 12 of the "Soil Venting Stack" stack.

Action: Click on the right-pointing arrow button. You are now at card 13 of the "Soil Venting Stack" stack. Read the text, then enter:

estimated spill mass = 4000 kg
desired remediation time = 180 d

Now click on the "-->Press to Get Rates<--" button

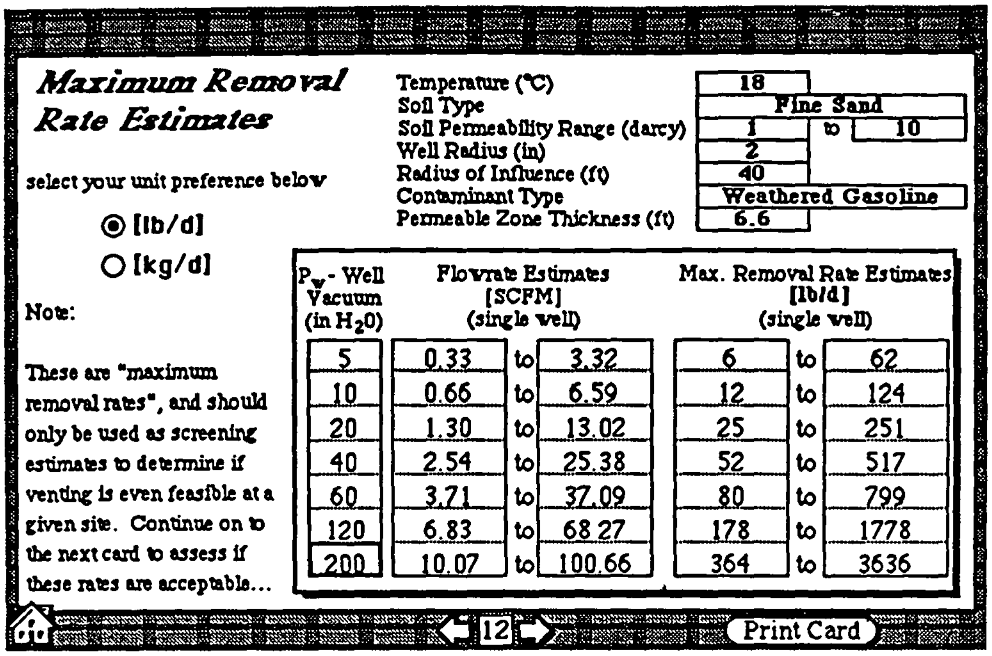


Figure 15. Card 12 of the "Soil Venting Stack" stack.

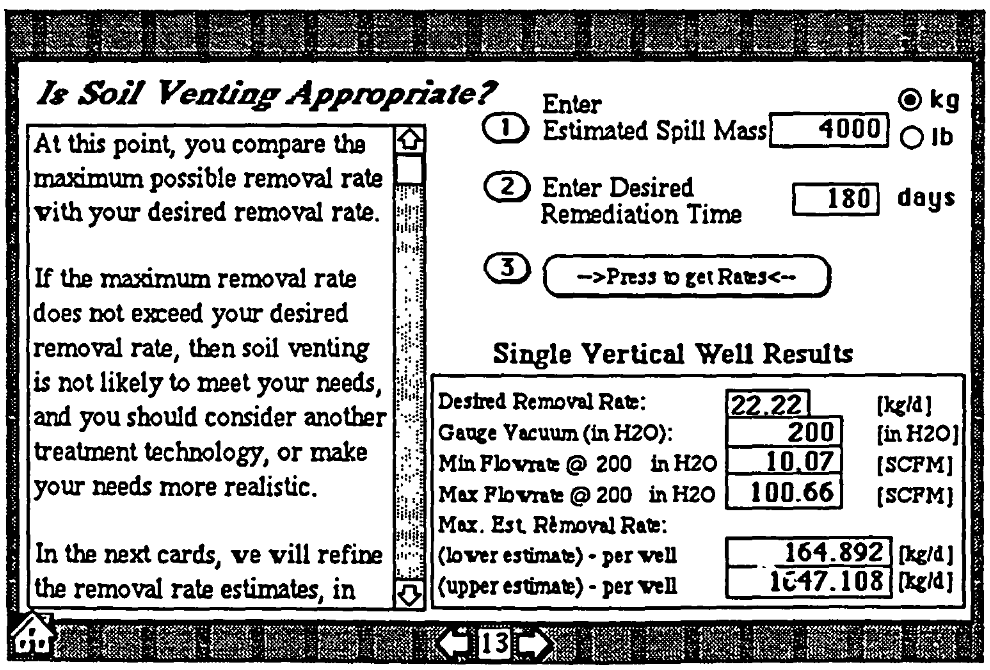


Figure 16. Card 13 of the "Soil Venting Stack" stack.

Result: Your screen should now look like Figure 16. Note that your desired removal rate (=22 kg/d) is less than the estimated maximum removal rates for a single vertical well (=165 to 1650 kg/d). At this point in the screening exercise, therefore, soil venting still appears to be a viable option.

Step 10: Location: Card 13 of the "Soil Venting Stack" stack.

Action: Click on the right-pointing arrow button to advance to card 14 of the "Soil Venting Stack" stack. Read the text, then advance to card 15 of the "Soil Venting Stack" by clicking on the right-pointing arrow button. Again, take the time to read the text, then advance to card 16 of the "Soil Venting Stack" stack. The focus of these cards is the prediction of vapor concentrations and removal rates as they change with time due to composition changes. It is important to try to understand the concepts introduced in these cards.

Result: You are at card 16 of the "Soil Venting Stack" stack (see Figure 17).

Step 11: Location: Card 16 of the "Soil Venting Stack" stack.

Action: This card is used to finalize your input data prior to calculating vapor concentration and residual soil contamination composition changes with time. Read the instructions in the order that they are numbered. Note that the summary table in the upper right corner of the card contains all the parameter values that you have input thus far. The instructions describe how to change these values, but at this point we will retain the displayed values. Because it is difficult to present the behavior of each compound in a mixture composed of an arbitrary number of compounds, the output is simplified by reporting the behavior in terms of "boiling point" ranges. This simply represents a summation of all compounds whose boiling points fall between pre-specified values. Presented in this fashion, the model results can be interpreted much more quickly. Click on the "tell me more about BP ranges..." button, read the help card, then return to card 16 of the "Soil Venting Stack" stack. Click on the "-->Set Default BP Ranges<--" button. Your screen should now look like Figure 17. Click on the "Generate Predictions" button

Result: The message "Sit Back and Relax..." will appear on your screen, followed by a screen on which the following appears:

"Copyright © Absoft Corp 1988
Copyright © Shell Oil Co 1990
HANG ON ----- YOU WILL BE RETURNED TO HYPERCARD...
OF COMPOUNDS IN LIBRARY = 62"

Then card 17 of the "Soil Venting Stack" stack will appear.

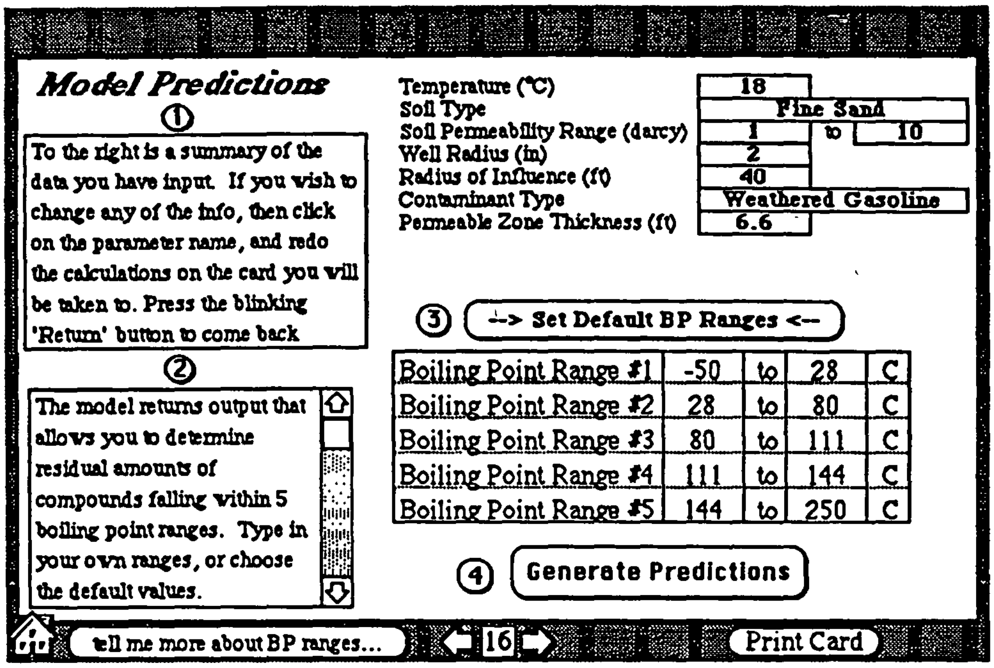


Figure 17. Card 16 of the "Soil Venting Stack" stack.

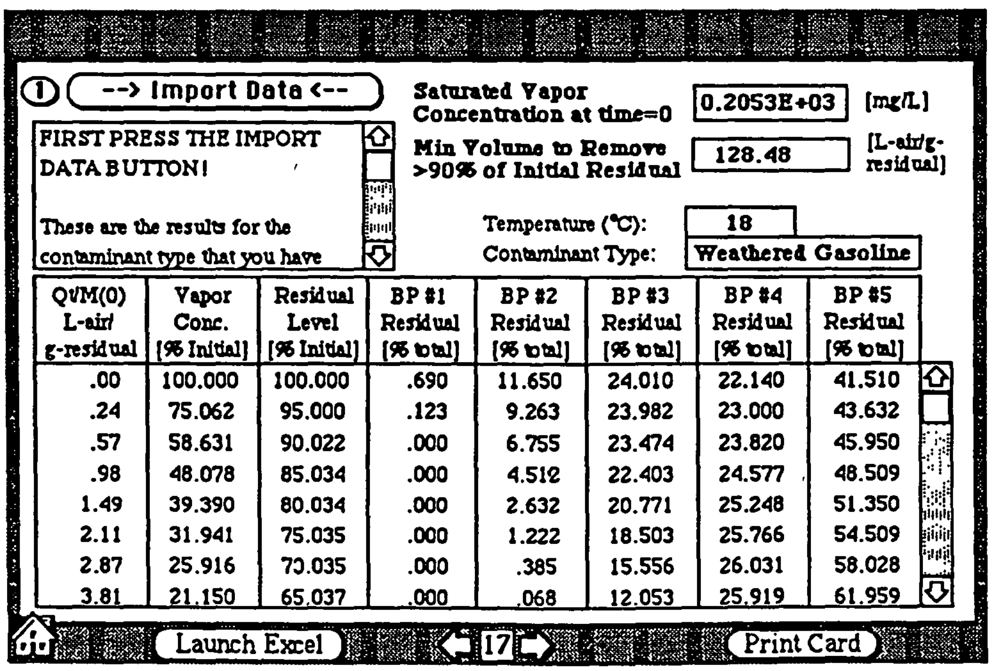


Figure 18. Card 17 of the "Soil Venting Stack" stack.

Step 12: Location: Card 17 of the "Soil Venting Stack" stack.
Action: Read the instructions, then click on the "-->Import Data<--" button.
Result: Your screen should look like Figure 18. The table in the lower part of the card lists model predictions: vapor concentration and residual soil concentration (expressed as a percentage of their initial values), as well as the composition of the residual (expressed as a percentage of the total for each boiling point range) as a function of the amount of air drawn through the contaminated soil. Note that as the volume of air drawn through the soil increases, the vapor concentration and residual soil levels decrease, and the composition of the residual becomes richer in the less volatile compounds (BP Range #5). In the upper right corner of the card are displayed the saturated, or initial, vapor concentration and the minimum amount of air that must be drawn through the soil per gram of initial contaminant to achieve at least a 90% reduction in the initial residual level. This value is used in future calculations as a design parameter.

Step 13: Location: Card 17 of the "Soil Venting Stack" stack.
Action: Click on the right-pointing arrow to advance to card 18 of the "Soil Venting Stack" stack.
Result: You are at card 18 of the "Soil Venting Stack" stack, which should resemble Figure 19. Read the text. A summary of your input parameters appears on the right side of this card. At the bottom appears two calculated values representing the range of the minimum number of wells required to achieve a 90% reduction in the initial residual level in the desired remediation time. These values correspond to idealized conditions, however, they can be used to gauge the efficacy of soil venting at your site. For example, in this case the minimum number of wells ranges between 0.7 - 7, which is not an unreasonable number for a site the size of a service station. If the range had been 100 - 1000, then it might be wise to consider other remediation options.

It is important to recognize that model predictions are intended to serve as guidelines, and are limited in their ability to describe behavior that might be observed at any given site. One should use all the information available, in addition to idealized model predictions to make rational decisions about the applicability of soil venting.

Step 14: Location: Card 18 of the "Soil Venting Stack" stack.

Action: Click on the right-pointing arrow button to advance to card 19.

Result: You are now at card 19 of the "Soil Venting Stack" stack. This card lists several phenomena that can cause one to achieve less than ideal removal rates. Take the time to explore each of these options, then return to card 19 of the "Soil Venting Stack" stack.

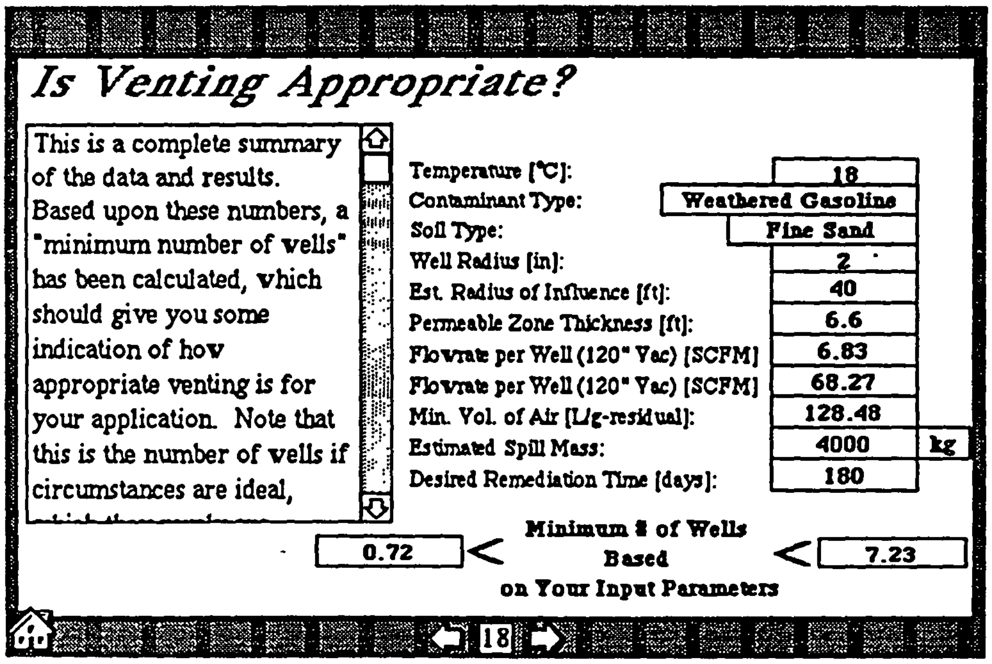


Figure 19. Card 18 of the "Soil Venting Stack" stack.

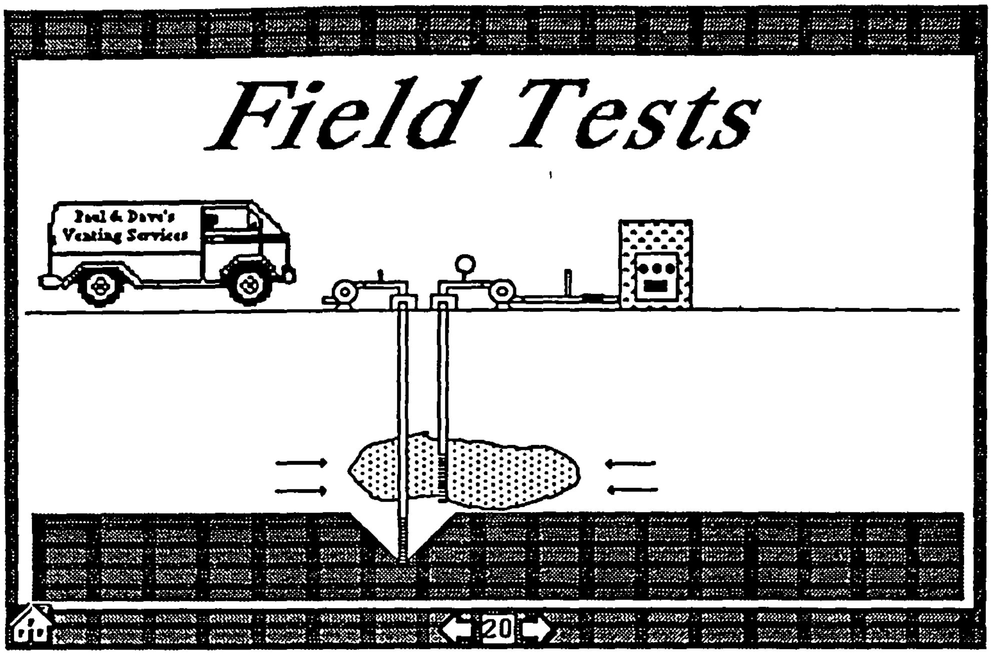


Figure 20. Card 20 of the "Soil Venting Stack" stack.

V.3.3 Sample Problem Exercise - Field Permeability Test.

Note: *It is recommended that you always plot and visually inspect your data prior to attempting to fit it to any theory.*

In this example, we use **HyperVentilate** to analyze air permeability test data from the site pictured in Figure 10. We will focus on results from the lower fine to medium sand zone (45 - 50 ft below ground surface). Advance to card 20 (Figure 20) of the "Soil Venting Stack" stack to begin.

Step 1:
- Location: Card 20 of the "Soil Venting Stack" stack.
- Action: Using the right-pointing arrow, advance to card 21 of the "Soil Venting Stack" stack. Read the text, then click on the "Air Permeability Test" button.
- Result: You are at card AP1 of the "Air Permeability Test" stack.

Step 2:
- Location: Card AP1 of the "Air Permeability Test" stack
- Action: Read the instructions, then click on the "Show Me Set-up" button. Take a look at the figure, then click the "Return" button to return to card AP1 of the "Air Permeability Test" stack. Now click on the "Test Instructions" button.
- Result: You are at card AP3 of the "Air Permeability Test" stack.

Step 3:
- Location: Card AP3 of the "Air Permeability Test" stack.

... the text, look at the sample data (click on the "show me sample data" button) then enter the following values for this example:

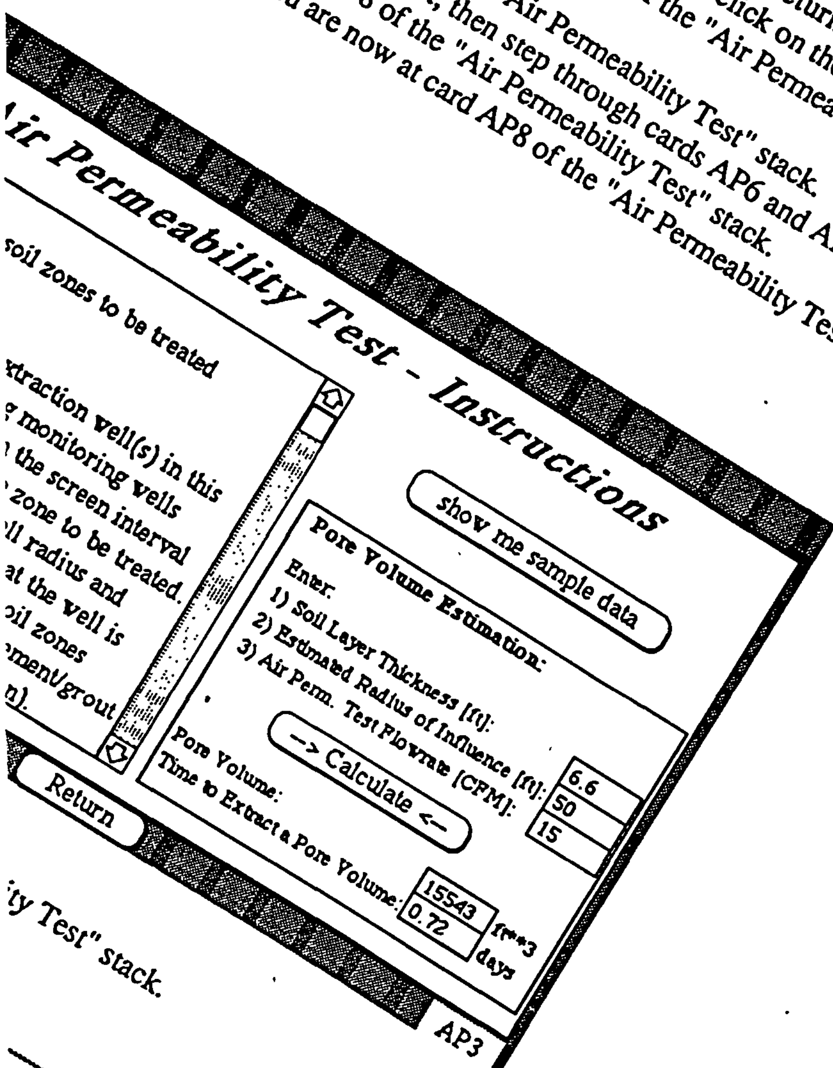
soil layer thickness = 6.6 ft
estimated radius of influence = 50 ft
air permeability test flowrate = 15 CFM

Click on the "-->Calculate<--" button to estimate how long the air permeability test should be conducted.

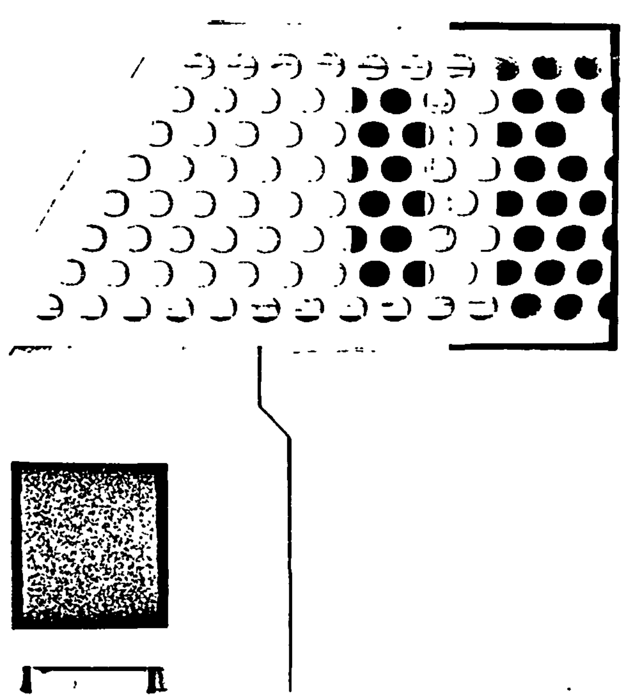
Result: Your results should match those displayed below in Figure 21.

Step 4: Location: Card AP3 of the "Air Permeability Test" stack.
Action: Click on the "Return" button to return to card AP1 of the "Air Permeability Test" stack. Then click on the "Data Analysis" button.
Result: You are now at card AP5 of the "Air Permeability Test" stack.

Step 5: Location: Card AP5 of the "Air Permeability Test" stack.
Action: Read the text, then step through cards AP6 and AP7, until you reach card AP8 of the "Air Permeability Test" stack.
Result: You are now at card AP8 of the "Air Permeability Test" stack.



...ity Test" stack.



Step 6: Location: Card AP8 of the "Air Permeability Test" stack.
Action: Read the text, click the "clear" buttons to clear any entries from columns, then enter the following data:

r = 53 ft		r = 32.4 ft	
Time [min]	Gauge Vacuum [in H_2O]	Time [min]	Gauge Vacuum [in H_2O]
9	0.1	4	1.2
11	0.2	7	3.0
15	0.2	9	4.3
23	0.4	12	5.5
30	0.7	16	6.9
40	1.3	24	9.9
100	2.8	30	11
		39	13
		52	16
		77	20
		99	21
		110	23
		121	24.5
		141	25.5

flowrate = 15 SCFM
screened interval thickness = 6.6 ft

While entering the data it is convenient to place the curser in the time column, type in the time value, then use the "tab" key to advance to the vacuum reading column. Enter the corresponding vacuum value, then hit the "tab key again. As you see, this advances the curser to the time column again. Now click the "-->Calculate<--" button.

Result: Your results should match those displayed in Figure 22. Soil permeability values have been calculated by fitting the field data to the theoretical model described in cards AP5 - AP7 of the "Air Permeability Test" stack.

Step 7: Location: Card AP8 of the "Air Permeability Test" stack.
Action: Review the results, then click on the "Explanation & Statistics" button. This advances you to card AP9 of the "Air Permeability Test" stack, which lists correlation coefficients for the data fitting process. These values give an indication of how well the model describes the behavior observed in the field. Values approaching unity indicate a good fit. Your results should match those given in Figure 23.

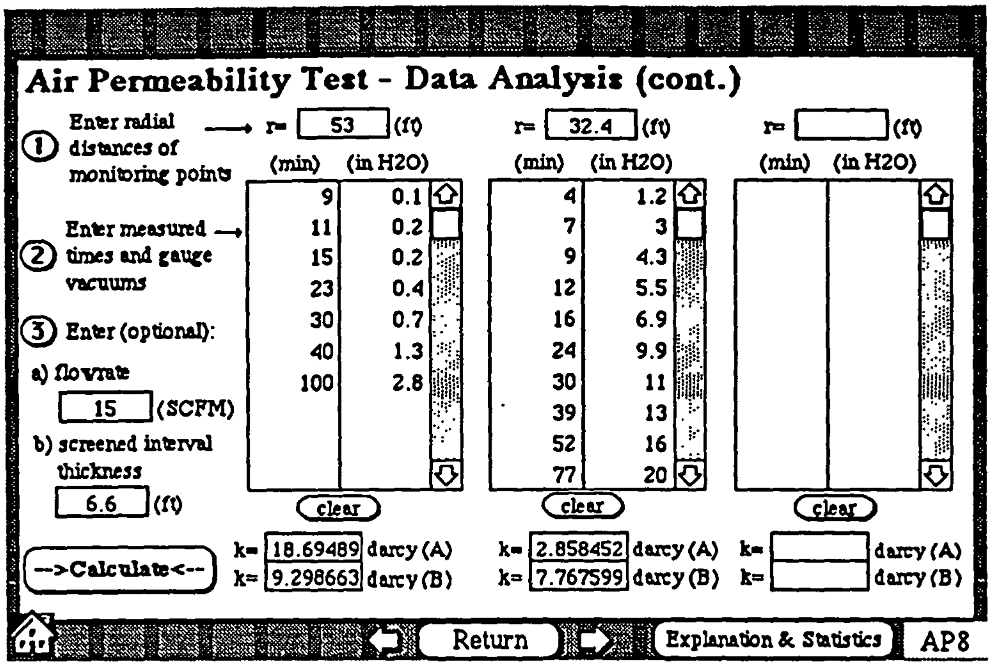


Figure 22. Card AP8 of the "Air Permeability Test" stack.

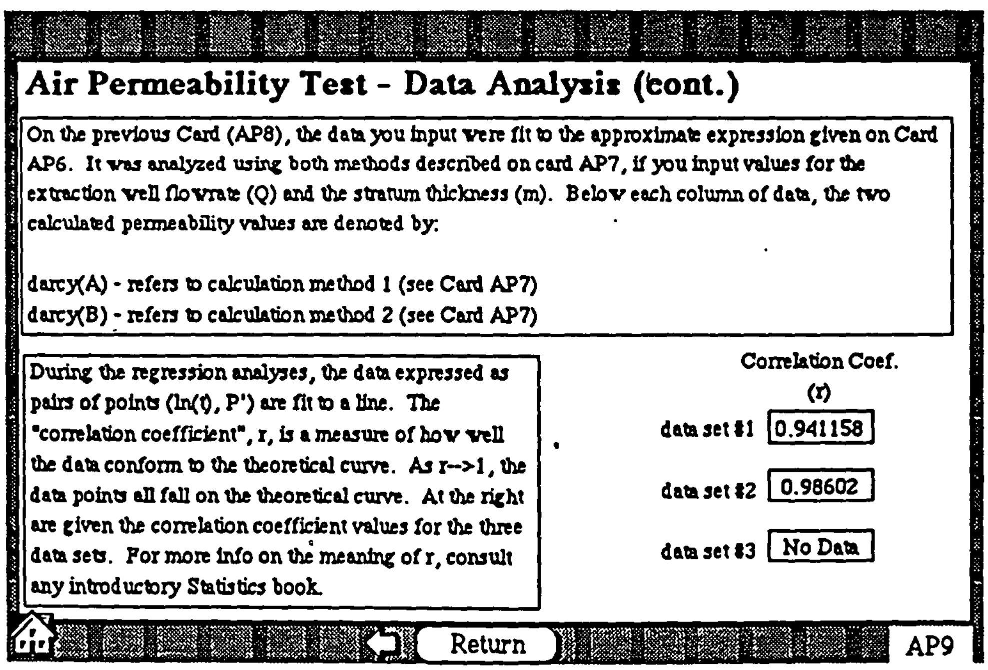


Figure 23. Card AP9 of the "Air Permeability Test" stack.

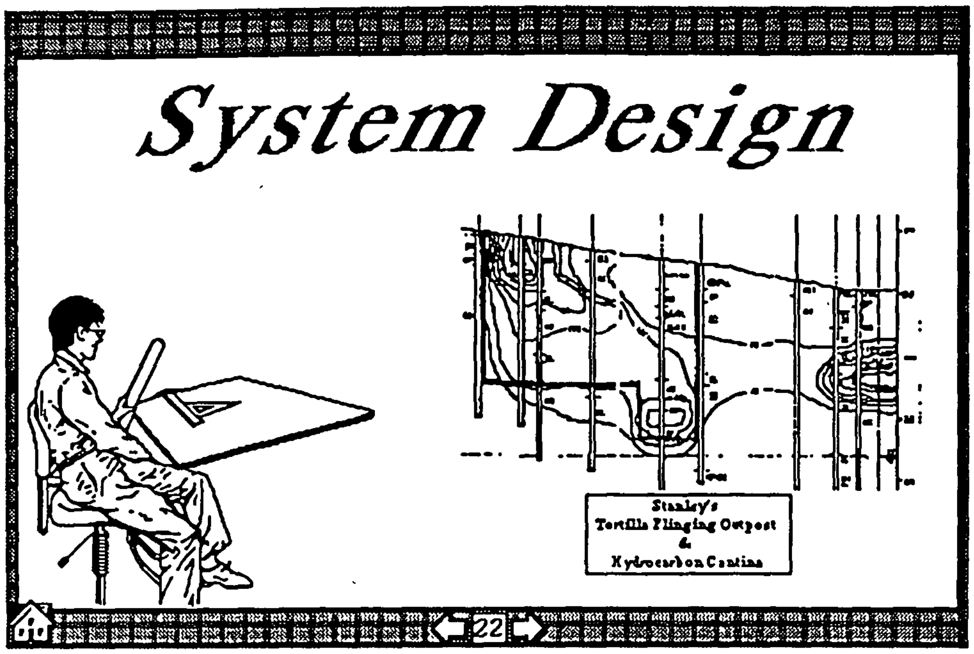


Figure 24. Card 22 of the "Soil Venting Stack" stack.

V.3.4 Sample Problem Exercise - System Design

In this example we illustrate the use of HyperVentilate for system design guidance. As in §V.3.2 and §V.3.3, we use the sample site presented in Figure 10. At this site gasoline was detected in three distinct soil strata: a fine to coarse zone located 10 - 30 ft below ground surface (BGS), a silty clay/clayey silt zone located 30 to 42 ft BGS, and a fine to medium sand zone that extends from 42 ft BGS to the deepest soil boring (60 ft BGS). Groundwater is detected in monitoring wells at about 50 ft BGS.

Advance to card 22 of the "Soil Venting Stack" stack to begin (Figure 24).

Step 1:
- Location: Card 22 of the "Soil Venting Stack" stack.
- Action: Use the right-pointing arrow to advance to card 23 of the "Soil Venting Stack" stack. Read the text, then advance to card 24 of the "Soil Venting Stack" stack.
- Result: Card 24 of the "Soil Venting Stack" stack, which appears in Figure 25, should be displayed.

Step 2:
- Location: Card 24 of the "Soil Venting Stack" stack.
- Action: Read the text, explore using some of the options. You will find that the options: "Well Location", "Well Construction", "Surface Seals", "Groundwater Pumping System", and "Vapor Treatment" provide some useful guidance information on aspects and components of a soil venting system. Return to card 24.
- Result: Card 24 of the "Soil Venting Stack" stack should be displayed.

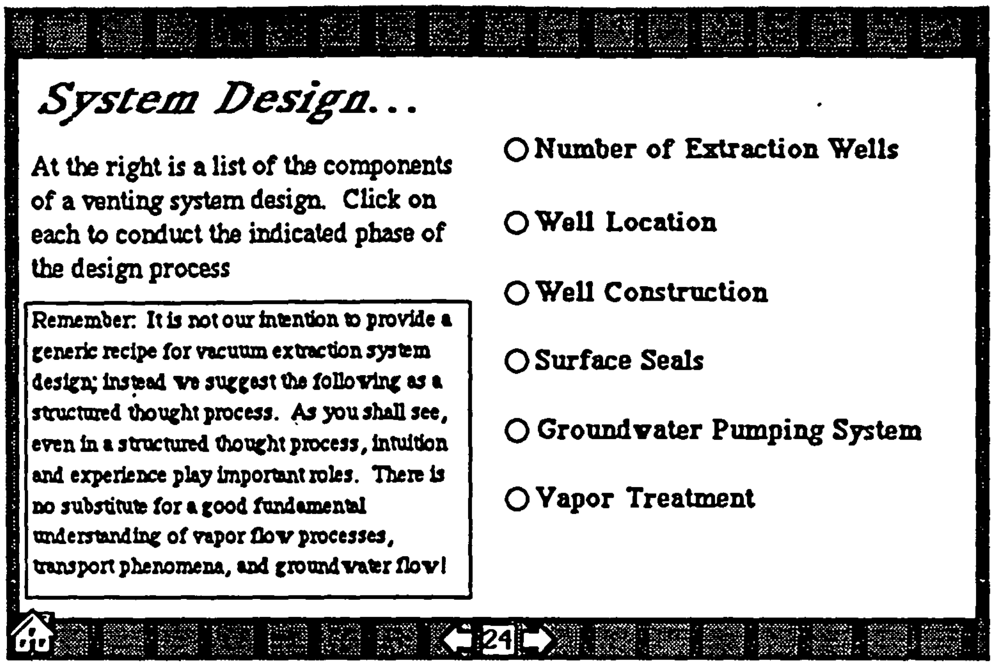


Figure 25. Card 24 of the "Soil Venting Stack" stack.

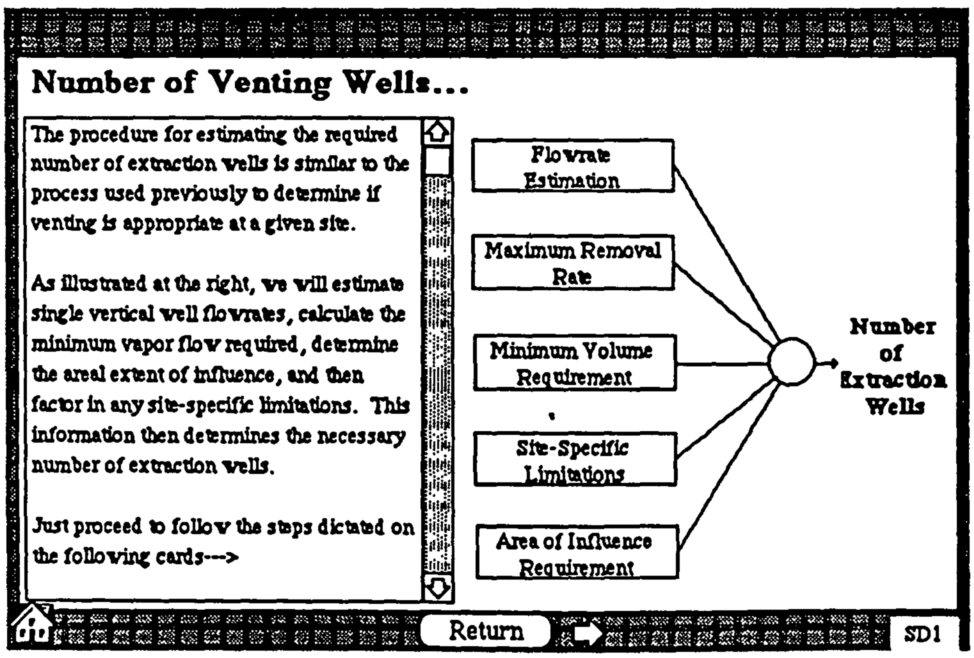


Figure 26. Card SD1 of the "System Design" stack.

Step 3: Location: Card 24 of the "Soil Venting Stack" stack.
Action: Select "Number of Extraction Wells" from the list of options.
Result: Card SD1 of the "System Design" stack should be displayed, as pictured in Figure 26.

Step 4: Location: Card SD1 of the "System Design" stack.
Action: Read the text, then use the right-pointing arrow to advance to card SD2.
Result: Card SD2 of the "System Design" stack should be displayed.

Step 5: Location: Card SD2 of the "System Design" stack.
Action: Read the instructions on the card, enter the following values into the table, then click on the "Update" button:

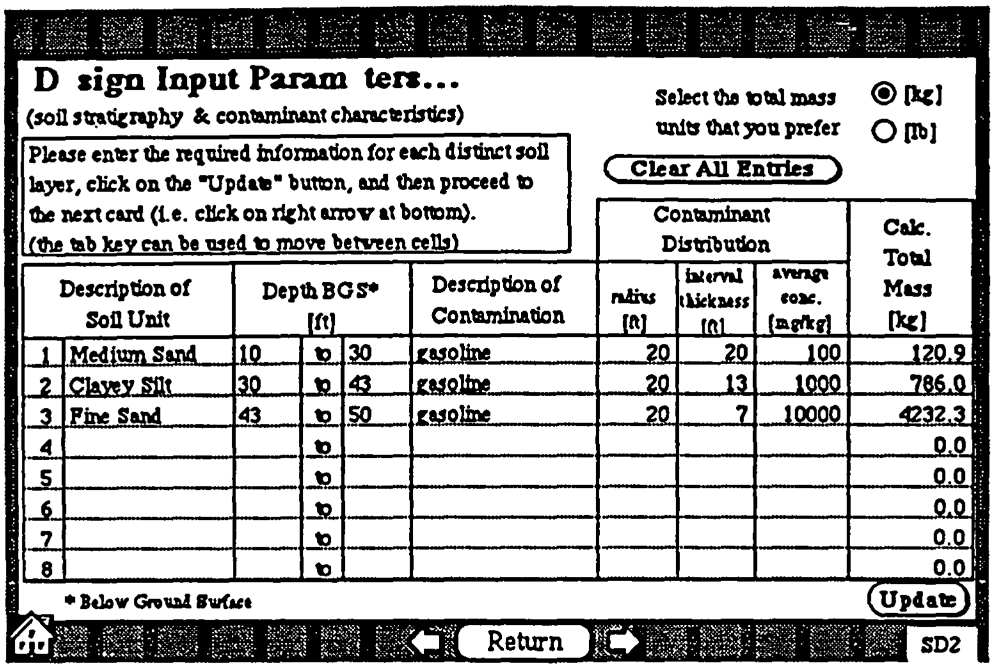
		Soil Zone	
Parameter	**Medium Sand**	**Clayey Silt**	**Fine Sand**
subsurface interval (ft BGS)	10 -30	30 - 43	43 - 50
description of contaminant	gasoline	gasoline	gasoline
radial extent of contamination (ft)	20	20	20
interval thickness (ft)	20	13	7
average contaminant concentration	100	1000	10000

Result: Card SD2 should now resemble Figure 27.

Step 6: Location: Card SD2 of the "System Design" stack.
Action: Use the right-pointing arrow to advance to card SD3 of the "System Design" stack.
Result: Card SD3 of the "System Design" stack should be displayed.

Step 7: Location: Card SD3 of the "System Design" stack.
Action: Read the text. Note that "clicking" on many of the table headings will take you to "help" cards. Take a few minutes to explore the use of these, then enter the following information:

		Soil Zone	
Parameter	**Medium Sand**	**Clayey Silt**	**Fine Sand**
permeability (darcy)	10 - 100	0.01 - 0.1	1 - 10
design vacuum (in H_2O)	40	40	40
Well Construction:			
Radius of Influence (ft)	40	40	40
Extraction Well Radius (in)	2	2	2
Extraction Well Screen Thickness (ft)	10	5	5



D sign Input Param ters...
(soil stratigraphy & contaminant characteristics)

Please enter the required information for each distinct soil layer, click on the "Update" button, and then proceed to the next card (i.e. click on right arrow at bottom).
(the tab key can be used to move between cells)

Select the total mass units that you prefer ◉ [kg] ○ [lb]

Clear All Entries

	Description of Soil Unit	Depth BGS* [ft]			Description of Contamination	Contaminant Distribution: radius [ft]	interval thickness [ft]	average conc. [mg/kg]	Calc. Total Mass [kg]
1	Medium Sand	10	to	30	gasoline	20	20	100	120.9
2	Clayey Silt	30	to	43	gasoline	20	13	1000	786.0
3	Fine Sand	43	to	50	gasoline	20	7	10000	4232.3
4			to						0.0
5			to						0.0
6			to						0.0
7			to						0.0
8			to						0.0

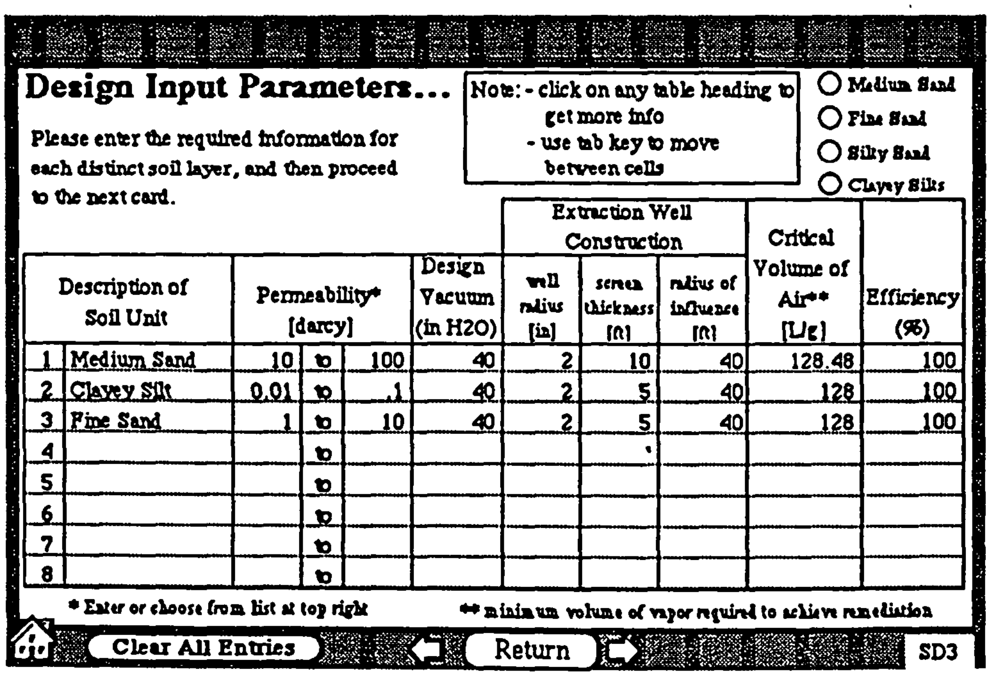
* Below Ground Surface

Update

Return

SD2

Figure 27. Card SD2 of the "System Design" stack.



Design Input Parameters...

Please enter the required information for each distinct soil layer, and then proceed to the next card.

Note: - click on any table heading to get more info
- use tab key to move between cells

○ Medium Sand
○ Fine Sand
○ Silty Sand
○ Clayey Silts

	Description of Soil Unit	Permeability* [darcy]			Design Vacuum (in H2O)	Extraction Well Construction: well radius [in]	screen thickness [ft]	radius of influence [ft]	Critical Volume of Air** [L/g]	Efficiency (%)
1	Medium Sand	10	to	100	40	2	10	40	128.48	100
2	Clayey Silt	0.01	to	.1	40	2	5	40	128	100
3	Fine Sand	1	to	10	40	2	5	40	128	100
4			to							
5			to							
6			to							
7			to							
8			to							

* Enter or choose from list at top right
** minimum volume of vapor required to achieve remediation

Clear All Entries

Return

SD3

Figure 28. Card SD3 of the "System Design" stack.

V

		The "Critical Volume of Air" is calculated by the same procedure used previously in §V.3.2 (steps 10 -13). To initiate this calculation, "click" on the "Critical Volume of Air**" heading.
	Result:	Card SD5 of the "System Design" stack appears on your screen (Figure 29).
Step 8:	Location:	Card SD5 of the "System Design" stack.
	Action:	Read the text carefully. The focus of this card is the prediction of vapor concentrations and removal rates as they change with time due to composition changes. It is important to try to understand the concepts introduced in this card. For more information, read the reference article contained in the appendix. Click on the "Do a Calculation" button to advance to card SD6 of the "System Design" stack (Figure 30).
	Result:	Card SD6 of the "System Design" stack appears on your screen.
Step 9:	Location:	Card SD6 of the "System Design" stack.
	Action:	This card is used to finalize your input data prior to calculating vapor concentration and residual soil contamination composition changes with time. Read the instructions in the order that they are numbered, then enter "18" for the temperature and select "weathered gasoline" from the three composition options. Because it is difficult to present the behavior of each compound in a mixture composed of an arbitrary number of compounds, the output is simplified by reporting the behavior in terms of "boiling point" ranges. This simply represents a summation of all compounds whose boiling points fall between pre-specified values. Presented in this fashion, the model results can be interpreted much more quickly. Click on the "tell me more about BP ranges..." button, read the help card, then return to card SD6 of the "System Design" stack. Click on the "-->Set Default BP Ranges<--" button. Your screen should now look like Figure 30. Click on the "Generate Predictions" button
	Result:	The message "Sit Back and Relax..." will appear on your screen, followed by a screen on which the following appears: "Copyright © Absoft Corp 1988 Copyright © Shell Oil Co 1990 HANG ON ----- YOU WILL BE RETURNED TO HYPERCARD... # OF COMPOUNDS IN LIBRARY = 62" Then card SD7 of the "System Design" stack will appear as shown in Figure 31.

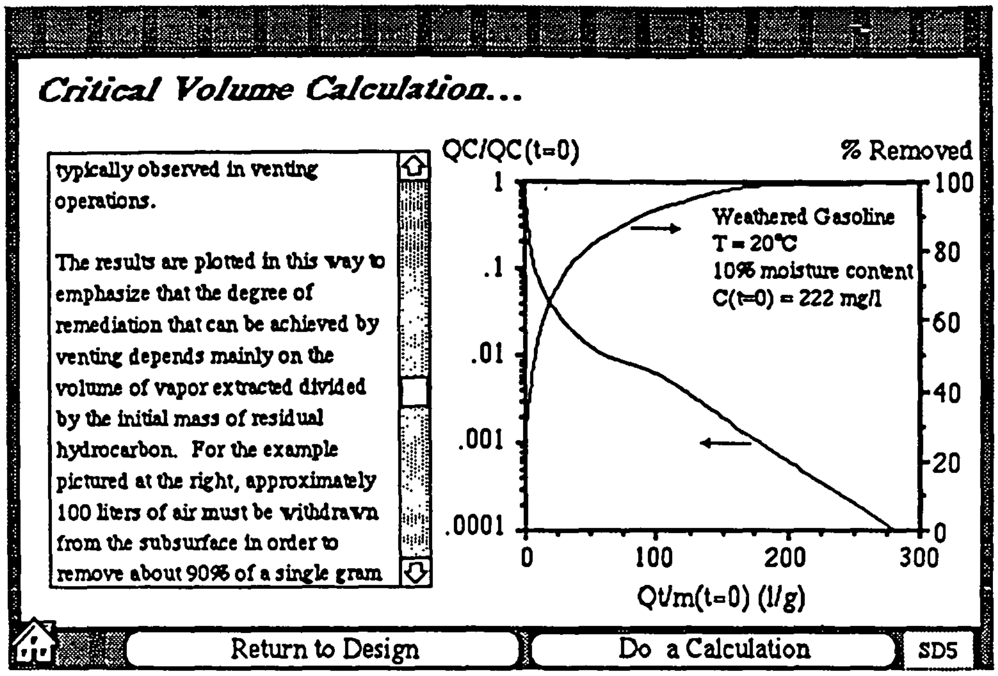


Figure 29. Card SD5 of the "System Design" stack.

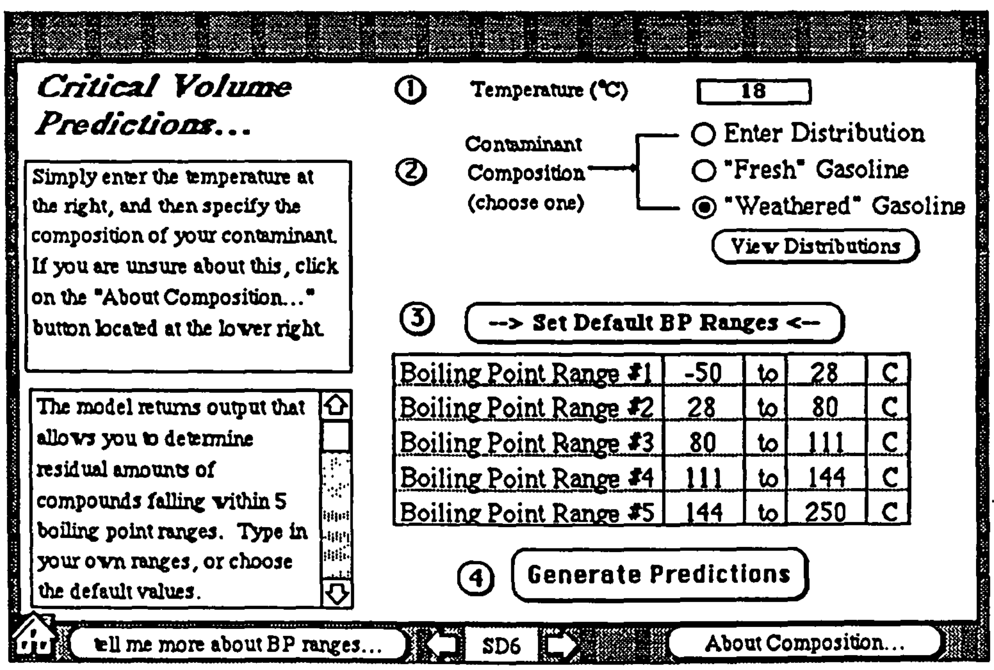


Figure 30. Card SD6 of the "System Design" stack.

V

Step 10: Location: Card SD7 of the "System Design" stack.
Action: Read the instructions, then click on the "-->Import Data<--" button.
Result: Your screen should look like Figure 31. The table in the lower part of the card lists model predictions: vapor concentration and residual soil concentration (expressed as a percentage of their initial values), as well as the composition of the residual (expressed as a percentage of the total for each boiling point range) as a function of the amount of air drawn through the contaminated soil. Note that as the volume of air drawn through the soil increases, the vapor concentration and residual soil levels decrease, and the composition of the residual becomes richer in the less volatile compounds (BP Range #5). In the upper right corner of the card are displayed the saturated, or initial, vapor concentration and the minimum amount of air that must be drawn through the soil per gram of initial contaminant to achieve at least a 90% reduction in the initial residual level. This value is used in future calculations as a design parameter.

Step 11: Location: Card SD7 of the "System Design" stack.
Action: Click on the "Return to System Design" button
Result: A dialog box will appear asking: "Transfer Critical Volume Value?". Click on the "Yes" button. You will now be prompted by another dialog box asking: "What soil unit # is this value for?". Enter "1" into the appropriate place then click on the "OK" button. You will now be transferred back to card SD3 of the "System Design" stack. Note that the value "128.48" has been entered into the "Critical Volume of Air**" column for the medium sand soil unit.

Step 12: Location: Card SD3 of the "System Design" stack.
Action: Enter "128" into the "Critical Volume of Air**" column for the clayey silt and fine sand soil units. For this example problem enter "100" for the efficiency in all three soil units
Result: Card SD3 should now resemble Figure 28.

Step 13: Location: Card SD3 of the "System Design" stack.
Action: Click on the right-pointing arrow at the bottom of the page to advance to Card SD4 of the "System Design" stack.
Result: Card SD4 of the "System Design" stack should appear on your screen.

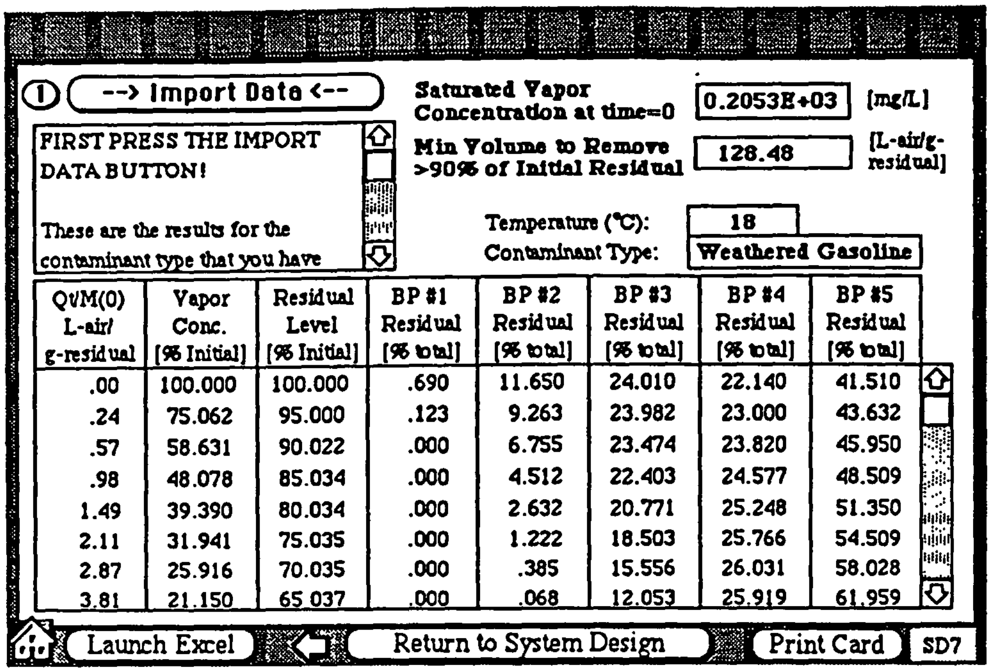
Step 14: Location: Card SD4 of the "System Design" stack.
Action: Assume that you wish to remediate this site in 180 days. Enter "180" in the "Time for Clean-up" column for each soil unit. Click on the "Update" button.
Result: **HyperVentilate** calculates a range of flowrates to a single vertical well, then uses this value and other input parameters to determine the minimum number of wells required based on two approaches.

∇

To read about these, click on the "Number of Wells" column heading. Your card SD4 should resemble Figure 32.

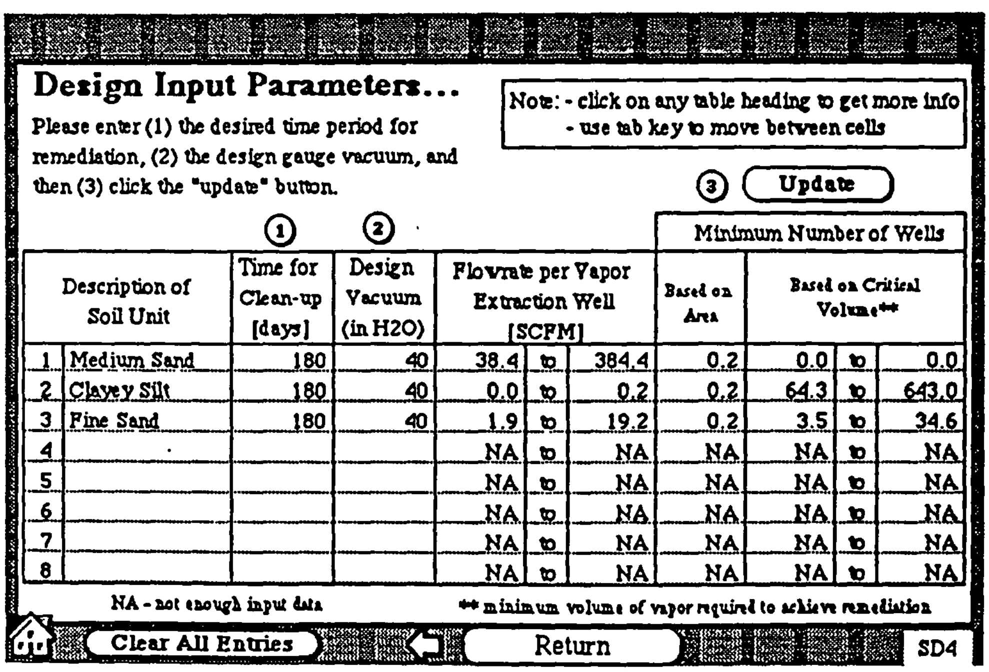
It is important to recognize that model predictions are intended to serve as guidelines, and are limited in their ability to describe behavior that might be observed at any given site. One should use all the information available, in addition to idealized model predictions to make rational decisions about the applicability of soil venting.

You can read about the effect of venting at this site in the article: "Soil Venting at a California Site: Field Data Reconciled with Theory", by P. C. Johnson, C. C. Stanley, D. L. Byers, D. A. Benson, and M. A. Acton, in *Hydrocarbon Contaminated Soils and Groundwater: Analysis, Fate, Environmental Health Effects, and Remediation Volume 1*, P. T. Kostecki and E. J. Calabrese, editors, Lewis Publishers, p.253 - 281, 1991.



Qt/M(0) L-air/ g-residual	Vapor Conc. [% Initial]	Residual Level [% Initial]	BP #1 Residual [% total]	BP #2 Residual [% total]	BP #3 Residual [% total]	BP #4 Residual [% total]	BP #5 Residual [% total]
.00	100.000	100.000	.690	11.650	24.010	22.140	41.510
.24	75.062	95.000	.123	9.263	23.982	23.000	43.632
.57	58.631	90.022	.000	6.755	23.474	23.820	45.950
.98	48.078	85.034	.000	4.512	22.403	24.577	48.509
1.49	39.390	80.034	.000	2.632	20.771	25.248	51.350
2.11	31.941	75.035	.000	1.222	18.503	25.766	54.509
2.87	25.916	70.035	.000	.385	15.556	26.031	58.028
3.81	21.150	65.037	.000	.068	12.053	25.919	61.959

Figure 31. Card SD7 of the "System Design" stack.



	Description of Soil Unit	Time for Clean-up [days]	Design Vacuum (in H2O)	Flowrate per Vapor Extraction Well [SCFM]			Based on Area	Based on Critical Volume**		
1	Medium Sand	180	40	38.4	to	384.4	0.2	0.0	to	0.0
2	Clayey Silt	180	40	0.0	to	0.2	0.2	64.3	to	643.0
3	Fine Sand	180	40	1.9	to	19.2	0.2	3.5	to	34.6
4				NA	to	NA	NA	NA	to	NA
5				NA	to	NA	NA	NA	to	NA
6				NA	to	NA	NA	NA	to	NA
7				NA	to	NA	NA	NA	to	NA
8				NA	to	NA	NA	NA	to	NA

Figure 32. Card SD4 of the "System Design" stack.

References

Hutzler, N. J., Murphy, B. E., and Gierke, J. S., State of Technology Review: Soil Vapor Extraction Systems, U.S.E.P.A, EPA/600/2-89/024, June 1989.

Johnson, P. C., Kemblowski, M. W., and Colthart, J. D., Practical Screening Models for Soil Venting Applications, NWWA/API Conference on Petroleum Hydrocarbons and Organic Chemicals in Groundwater, Houston, TX, 1988.

Johnson, P. C., Stanley, C. C., Kemblowski, M., W., Byers, D. L., and Colthart, J. D., A Practical Approach to the Design, Operation, and Monitoring of In Situ Soil Venting Systems, to appear in Ground Water Monitoring Review, Spring 1990.

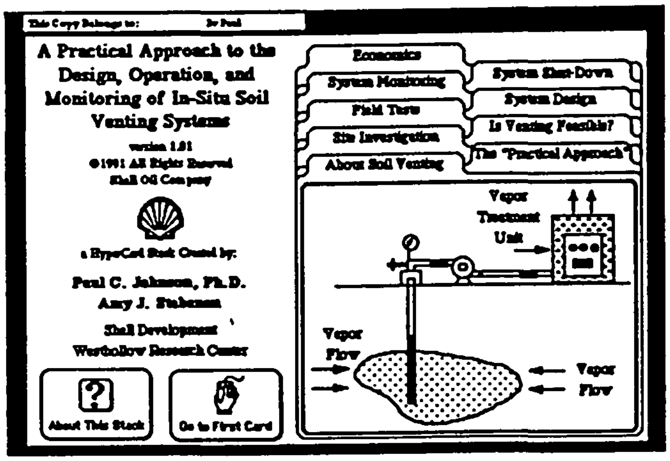
Marley, M. C., and Hoag, G. E., Induced Soil Venting for the Recovery/Restoration of Gasoline Hydrocarbons in the Vadose Zone, NWWA/API Conference on Petroleum Hydrocarbons and Organic Chemicals in Groundwater, Houston, TX, 1984.

Marley, M. C., Baehr, A. L., and Hult, M. F., Evaluation of Air-Permeability in the Unsaturated Zone using Pneumatic Pump Tests: 1. Theoretical Considerations, in review, 1990.

Thornton, J. S. and Wootan, W. L., Venting for the Removal of Hydrocarbon Vapors from Gasoline Contaminated Soil, J. Environ. Sci. Health, A17(1), 31-44, 1982.

Newell, C. J., Haasbeek, J. F., and Bedient, P. B., OASIS: A Graphical Decision Support System for Ground-Water Contaminant Modeling, Ground Water, 28 (2), 224 - 234, March - April 1990.

Appendix A: "Soil Venting Stack" stack cards.


This Copy Belongs to:
A Practical Approach to the Design, Operation, and Monitoring of In-Situ Soil Venting Systems
version 1.01
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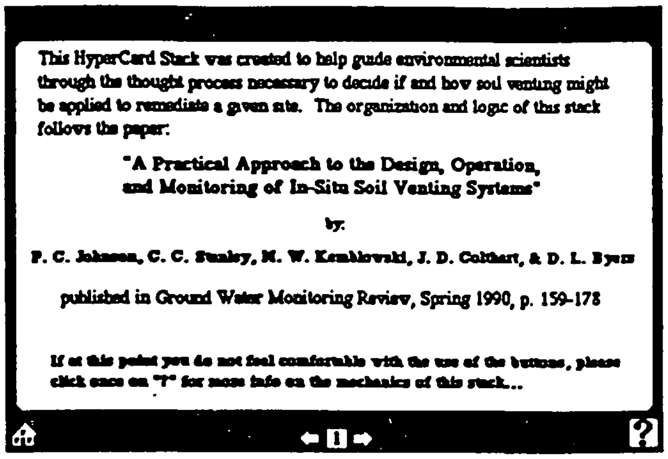
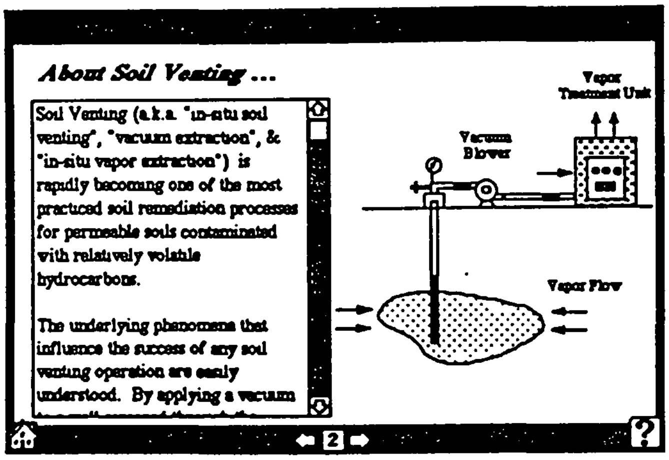
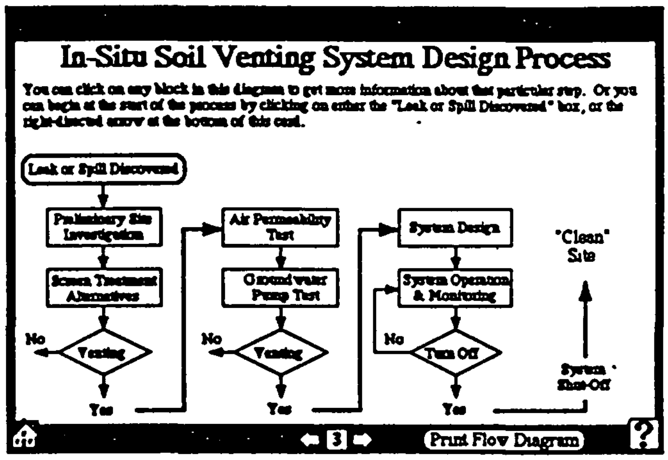
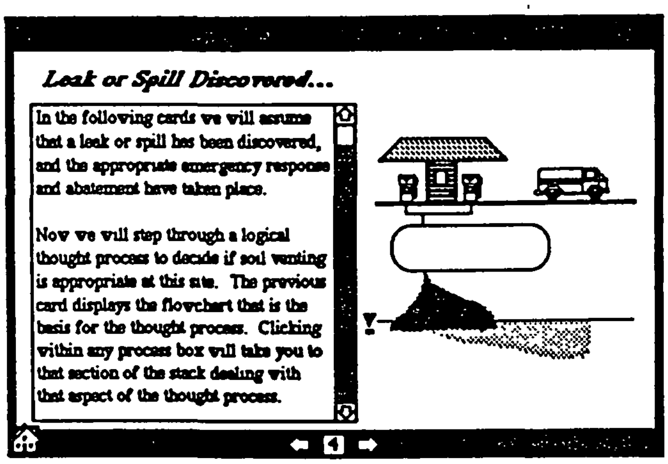
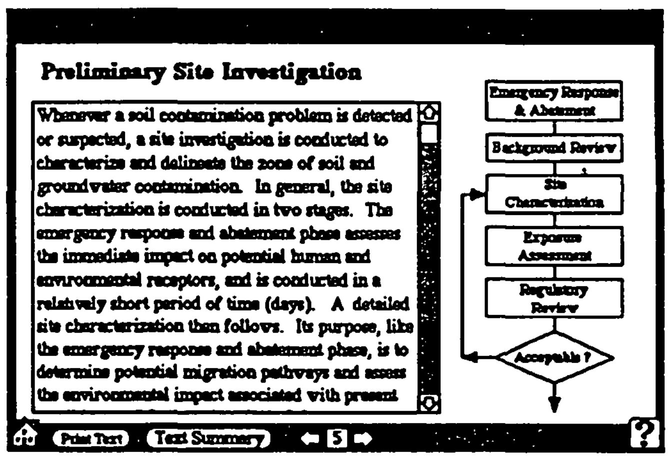
a HyperCard Stack Created by:
Paul C. Johnson, Ph.D.
Amy J. Stabenau
Shell Development
Westhollow Research Center
About This Stack
Go to First Card
Economics
System Monitoring
Field Tests
Site Investigation
About Soil Venting
System Shut-Down
System Design
Is Venting Feasible?
The "Practical Approach"
Vapor Treatment Unit
Vapor Flow
Vapor Flow

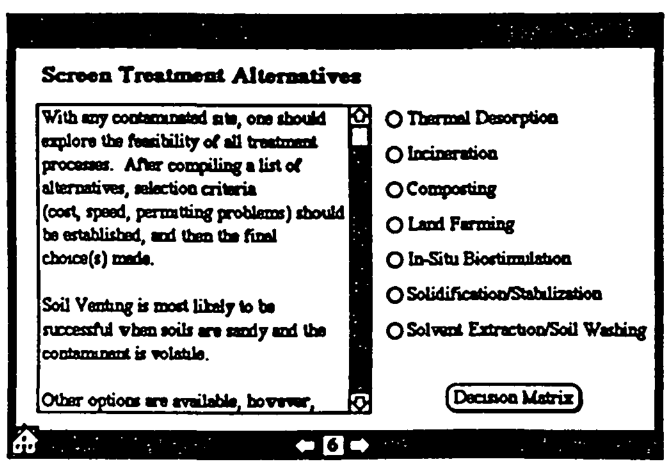

This HyperCard Stack was created to help guide environmental scientists through the thought process necessary to decide if and how soil venting might be applied to remediate a given site. The organization and logic of this stack follows the paper:
"A Practical Approach to the Design, Operation, and Monitoring of In-Situ Soil Venting Systems"
by:
P. C. Johnson, C. C. Stanley, M. W. Kemblowski, J. D. Colthart, & D. L. Byers
published in Ground Water Monitoring Review, Spring 1990, p. 159-178
If at this point you do not feel comfortable with the use of the buttons, please click once on "?" for more info on the mechanics of this stack...
1

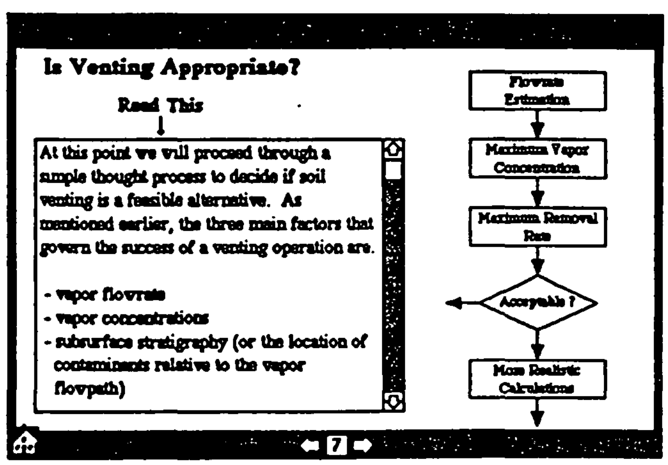

About Soil Venting ...
Soil Venting (a.k.a. "in-situ soil venting", "vacuum extraction", & "in-situ vapor extraction") is rapidly becoming one of the most practiced soil remediation processes for permeable soils contaminated with relatively volatile hydrocarbons.
The underlying phenomena that influence the success of any soil venting operation are easily understood. By applying a vacuum
Vapor Treatment Unit
Vacuum Blower
Vapor Flow
2


In-Situ Soil Venting System Design Process
You can click on any block in this diagram to get more information about that particular step. Or you can begin at the start of the process by clicking on either the "Leak or Spill Discovered" box, or the right-directed arrow at the bottom of this card.
Leak or Spill Discovered
Preliminary Site Investigation
Screen Treatment Alternatives
Venting
No
Yes
Air Permeability Test
Groundwater Pump Test
Venting
No
Yes
System Design
System Operation & Monitoring
Turn Off
No
Yes
"Clean" Site
System Shut-Off
3
Print Flow Diagram


Leak or Spill Discovered...
In the following cards we will assume that a leak or spill has been discovered, and the appropriate emergency response and abatement have taken place.
Now we will step through a logical thought process to decide if soil venting is appropriate at this site. The previous card displays the flowchart that is the basis for the thought process. Clicking within any process box will take you to that section of the stack dealing with that aspect of the thought process.
4


Preliminary Site Investigation
Whenever a soil contamination problem is detected or suspected, a site investigation is conducted to characterize and delineate the zone of soil and groundwater contamination. In general, the site characterization is conducted in two stages. The emergency response and abatement phase assesses the immediate impact on potential human and environmental receptors, and is conducted in a relatively short period of time (days). A detailed site characterization then follows. Its purpose, like the emergency response and abatement phase, is to determine potential migration pathways and assess the environmental impact associated with present
Emergency Response & Abatement
Background Review
Site Characterization
Exposure Assessment
Regulatory Review
Acceptable ?
Print Text
Text Summary
5


Screen Treatment Alternatives
With any contaminated site, one should explore the feasibility of all treatment processes. After compiling a list of alternatives, selection criteria (cost, speed, permitting problems) should be established, and then the final choice(s) made.
Soil Venting is most likely to be successful when soils are sandy and the contaminant is volatile.
Other options are available, however,
Thermal Desorption
Incineration
Composting
Land Farming
In-Situ Biostimulation
Solidification/Stabilization
Solvent Extraction/Soil Washing
Decision Matrix
6


Is Venting Appropriate?
Read This
At this point we will proceed through a simple thought process to decide if soil venting is a feasible alternative. As mentioned earlier, the three main factors that govern the success of a venting operation are.
- vapor flowrate
- vapor concentrations
- subsurface stratigraphy (or the location of contaminants relative to the vapor flowpath)
Flowrate Estimation
Maximum Vapor Concentration
Maximum Removal Rate
Acceptable ?
More Realistic Calculations
7

Flowrate Estimation:

1) Choose Soil Type, or
Optional - Enter your own permeability values (darcy)
2) Enter Well Radius (in)
3) Enter Radius of Influence (ft) & Interval Thickness*
4) Optional - Enter your own well vacuum (406" = max)
5) Click button to calculate Predicted Flowrate Ranges

- ○ Medium Sand
- Fine Sand
- ○ Silty Sand
- ○ Clayey Silts
- ○ Input Your Own Permeability Range

Permeability Range [1] to [10]

Well Radius [2] in
Radius of Influence [40] ft
Interval Thickness* [6.6] ft

—>Calculate Flowrate Ranges<—

* thickness of screened interval, or permeable zone (whichever is smaller).

Predicted Flowrate Ranges

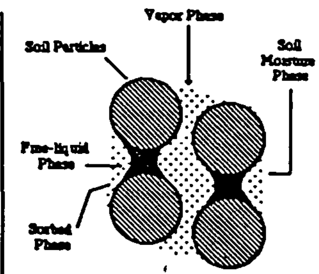
Well Vacuum P_w (in H_2O)	Flowrate (SCFM) (single well)		
5	0.33	to	3.32
10	0.66	to	6.59
20	1.30	to	13.02
40	2.54	to	25.38
60	3.71	to	37.09
120	6.83	to	68.27
200	10.07	to	100.66

About Soils (& Unit Conversions) ⇦ 8 ⇨ Info about Calculation

Vapor Concentration Estimation:

The maximum achievable removal rate occurs whenever the vapors removed by venting are "saturated" or in equilibrium with the contaminant/soil matrix.

In the next card you will estimate the maximum vapor concentration of your contaminant. Just follow the instructions in the upper left corner of the next card.



⇦ 9 ⇨

Vapor Concentration Estimation - Calculation

(1) Type in Temperature (°C) (hit <return>) [20]

(2) Click to Enter Composition of Contaminant or Choose one of the Default Distributions
- ○ Enter Distribution
- ○ "Fresh" Gasoline
- ◉ "Weathered" Gasoline

(3) Click to View Distributions, (optional) (View Distributions)

(4) Click to Perform Calculations ○ Perform Calculations

Results

Sum of Mass Fractions [ ]
Calc. Vapor Pressure [ ] atm
Calc. Vapor Concentration [ ] mg/l

How Do I Measure a Distribution? ⇦ 10 ⇨ About Calculation Print Card

Removal Rate Estimates

The maximum achievable removal rate occurs whenever the vapors removed by venting are "saturated" or in equilibrium with the contaminant/soil matrix.

The "Removal Rate" is simply the product of the flowrate times the vapor concentration. The values you input on Cards 8 & 10 will be used to generate removal rate estimates.

Maximum Removal Rate = Maximum Vapor Concentration x Estimated Vapor Flowrate

We calculate this "maximum" removal rate to determine if, even under the best conditions (saturated vapors & no composition changes w/time), venting can meet your needs.

Click on the button below to generate these values...

(Calculate Estimates)

⇦ 11 ⇨

Maximum Removal Rate Estimates

select your unit preference below

[lb/d]

○ [kg/d]

Now:

These are "maximum removal rates", and should only be used as screening estimates to determine if venting is even feasible at a given site. Continue on to the next card to assess if these rates are acceptable...

Temperature (°C)	18
Soil Type	Fine Sand
Soil Permeability Range (darcy)	1 to 10
Well Radius (in)	2
Radius of Influence (ft)	40
Contaminant Type	Weathered Gasoline
Permeable Zone Thickness (ft)	6.6

P_w - Well Vacuum (in H_2O)	Flowrate Estimates [SCFM] (single well)			Max. Removal Rate Estimates [lb/d] (single well)		
5	0.33	to	3.32	6	to	62
10	0.66	to	6.59	12	to	124
20	1.30	to	13.02	25	to	251
40	2.54	to	25.38	52	to	517
60	3.71	to	37.09	80	to	799
120	6.83	to	68.27	178	to	1778
200	10.07	to	100.66	364	to	3636

⇦ 12 ⇨ Print Card

Is Soil Venting Appropriate?

At this point, you compare the maximum possible removal rate with your desired removal rate.

If the maximum removal rate does not exceed your desired removal rate, then soil venting is not likely to meet your needs, and you should consider another treatment technology, or make your needs more realistic.

In the next cards, we will refine

(1) Enter Estimated Spill Mass [4000] ◉ kg ○ lb

(2) Enter Desired Remediation Time [180] days

(3) (—>Press to get Rates<—)

Single Vertical Well Results

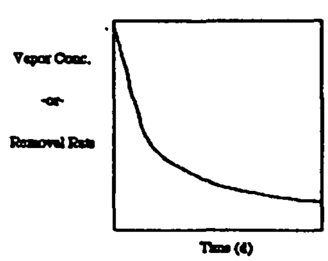
Desired Removal Rate:	22.2	[kg/d]
Gauge Vacuum (in H2O):	200	[in H2O]
Min Flowrate @ 200 in H2O	10.07	[SCFM]
Max Flowrate @ 200 in H2O	100.66	[SCFM]
Max. Est. Removal Rate:		
(lower estimate) - per well	164.892	[kg/d]
(upper estimate) - per well	1647.108	[kg/d]

⇦ 13 ⇨

Is Soil Venting Appropriate? - Refined Estimates

The preceding estimates are useful only as a "first cut", and should be refined if venting is still a potentially feasible option.

Typically during soil venting, the measured vapor concentration and removal rate dependence on time resembles the plot on the right (when the total vapor flowrate is relatively constant).

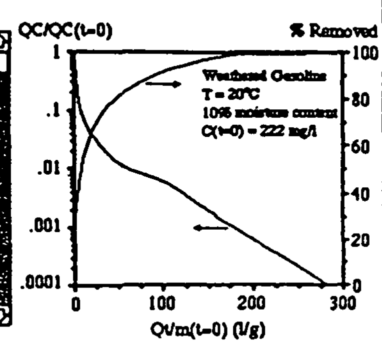


⇦ 14 ⇨

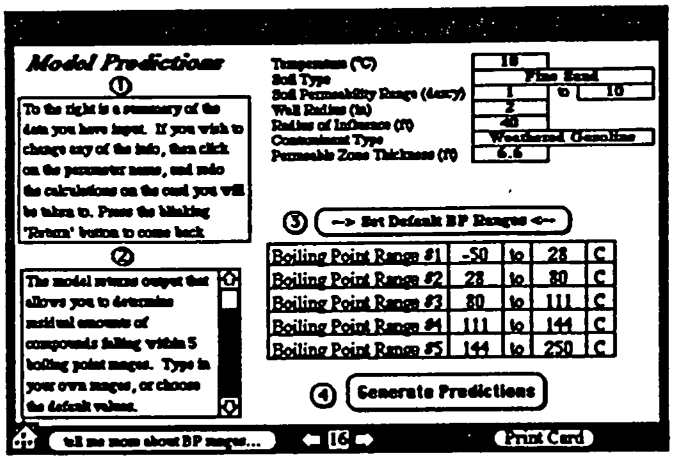
More Detailed Calculations

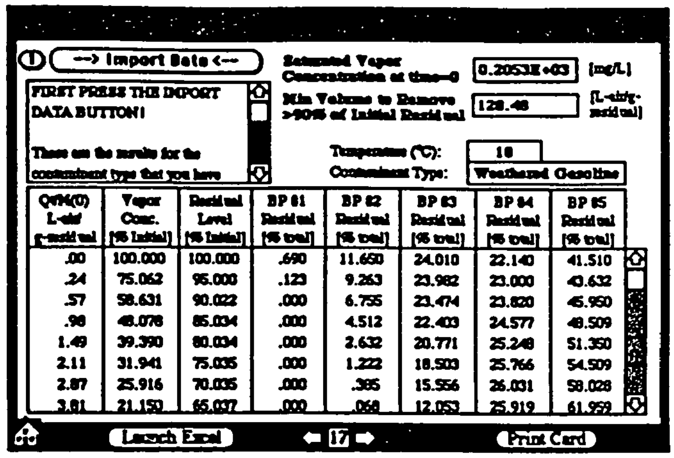
Pictured at the right are the results of sample model predictions, for a weathered gasoline sample.

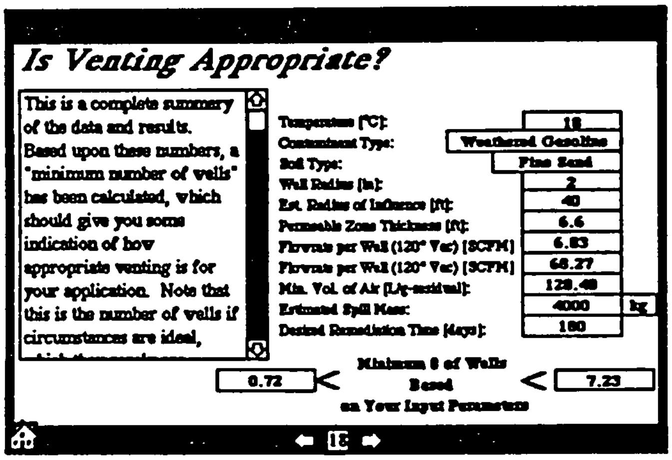
The vertical axis represents either normalized concentrations [C(t)/C(t=0)], or normalized removal rates [QC(t)/QC(t=0)], while the horizontal axis represents the total volume of vapor

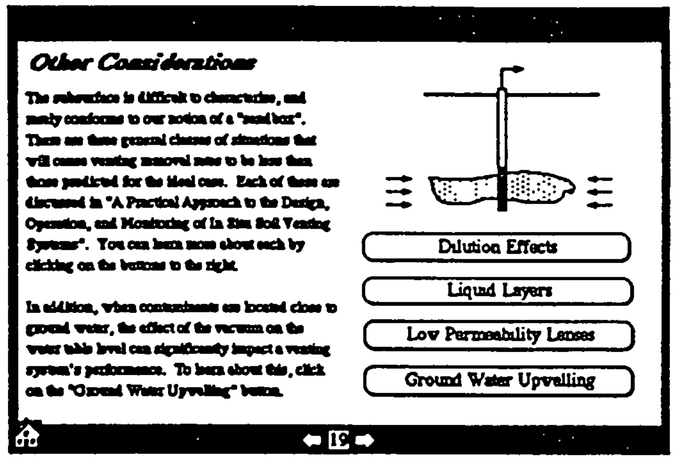


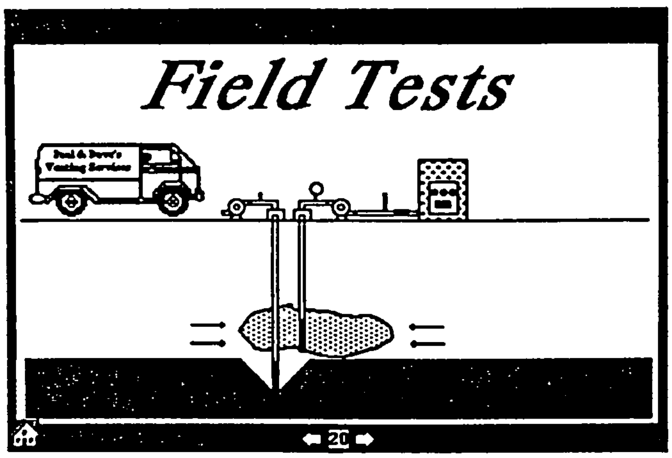
⇦ 15 ⇨

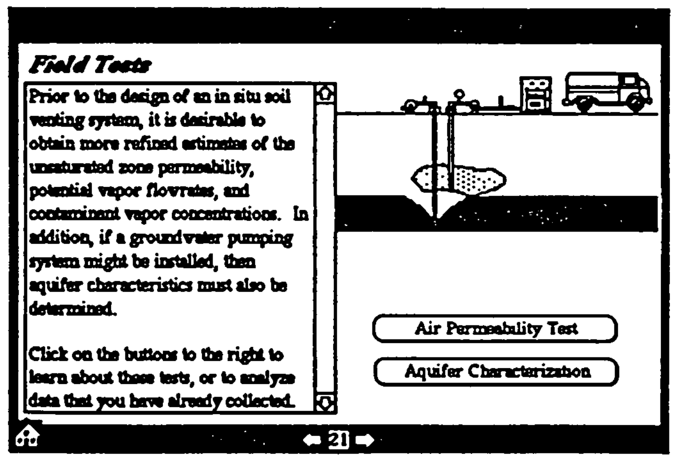

Model Predictions
①
To the right is a summary of the data you have input. If you wish to change any of the info, then click on the parameter name, and redo the calculations on the card you will be taken to. Press the blinking 'Return' button to come back
②
The model returns output that allows you to determine residual amounts of compounds falling within 5 boiling point ranges. Type in your own ranges, or choose the default values.
Temperature (°C) 18
Soil Type Fine Sand
Soil Permeability Range (darcy) 1 to 10
Well Radius (in) 2
Radius of Influence (ft) 40
Contaminant Type Weathered Gasoline
Permeable Zone Thickness (ft) 6.6
③ --> Set Default BP Ranges <--
Boiling Point Range #1 -50 to 28 C
Boiling Point Range #2 28 to 80 C
Boiling Point Range #3 80 to 111 C
Boiling Point Range #4 111 to 144 C
Boiling Point Range #5 144 to 250 C
④ Generate Predictions
tell me more about BP ranges...
16
Print Card

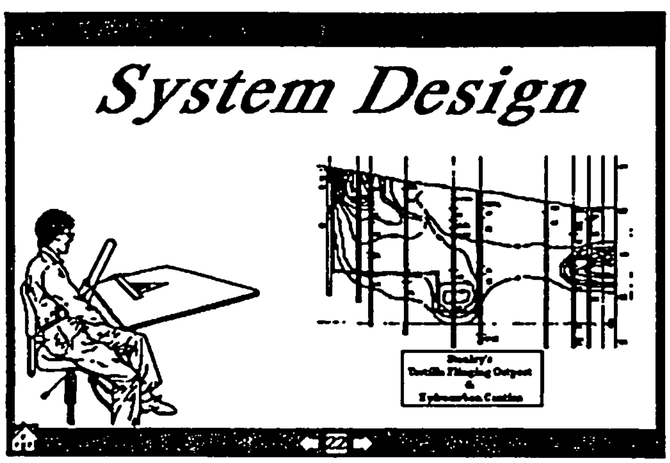

① --> Import Data <--
FIRST PRESS THE IMPORT DATA BUTTON!
These are the results for the contaminant type that you have
Saturated Vapor Concentration at time=0 0.2053E+03 [mg/L]
Min Volume to Remove >90% of Initial Residual 128.48 [L-air/g-residual]
Temperature (°C): 18
Contaminant Type: Weathered Gasoline
Q*t/M(0) L-air/ g-residual | Vapor Conc. [% Initial] | Residual Level [% Initial] | BP #1 Residual [% total] | BP #2 Residual [% total] | BP #3 Residual [% total] | BP #4 Residual [% total] | BP #5 Residual [% total]
.00 100.000 100.000 .690 11.650 24.010 22.140 41.510
.24 75.062 95.000 .123 9.263 23.982 23.000 43.632
.57 58.631 90.022 .000 6.755 23.474 23.820 45.950
.98 48.076 85.034 .000 4.512 22.403 24.577 48.509
1.49 39.390 80.034 .000 2.632 20.771 25.248 51.350
2.11 31.941 75.035 .000 1.222 18.503 25.766 54.509
2.87 25.916 70.035 .000 .385 15.556 26.031 58.028
3.81 21.150 65.037 .000 .068 12.053 25.919 61.959
Launch Excel
17
Print Card

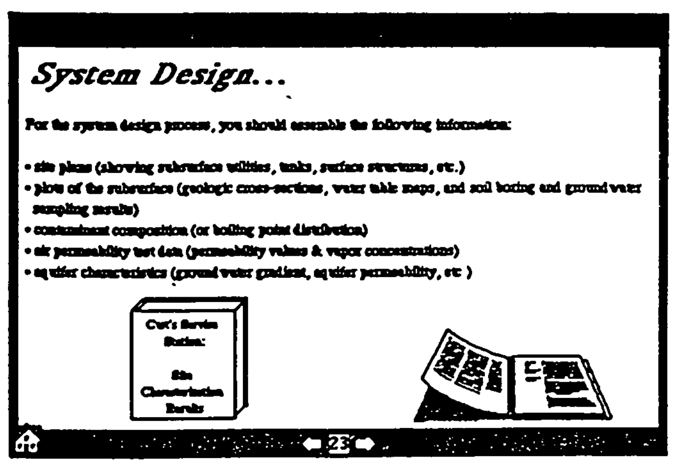

Is Venting Appropriate?
This is a complete summary of the data and results. Based upon these numbers, a "minimum number of wells" has been calculated, which should give you some indication of how appropriate venting is for your application. Note that this is the number of wells if circumstances are ideal,
Temperature [°C]: 18
Contaminant Type: Weathered Gasoline
Soil Type: Fine Sand
Well Radius [in]: 2
Est. Radius of Influence [ft]: 40
Permeable Zone Thickness [ft]: 6.6
Flowrate per Well (120" Vac) [SCFM] 6.83
Flowrate per Well (120" Vac) [SCFM] 68.27
Min. Vol. of Air [L/g-residual]: 128.48
Estimated Spill Mass: 4000 kg
Desired Remediation Time [days]: 180
0.72 < Minimum # of Wells Based on Your Input Parameters < 7.23
18

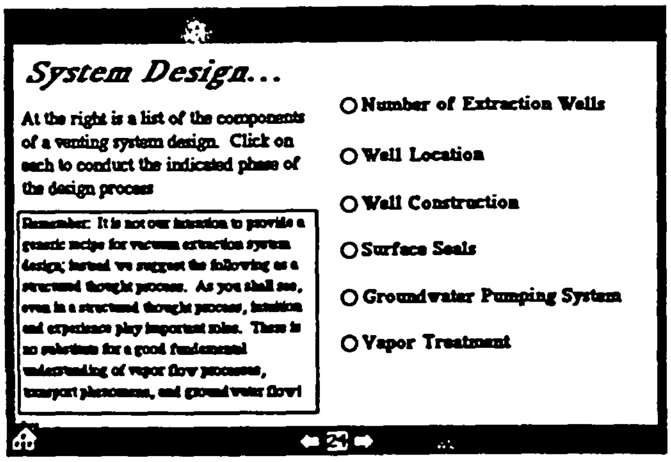

Other Considerations
The subsurface is difficult to characterize, and rarely conforms to our notion of a "sand box". There are three general classes of situations that will cause venting removal rates to be less than those predicted for the ideal case. Each of these are discussed in "A Practical Approach to the Design, Operation, and Monitoring of In Situ Soil Venting Systems". You can learn more about each by clicking on the buttons to the right.
In addition, when contaminants are located close to ground water, the effect of the vacuum on the water table level can significantly impact a venting system's performance. To learn about this, click on the "Ground Water Upwelling" button.
Dilution Effects
Liquid Layers
Low Permeability Lenses
Ground Water Upwelling
19

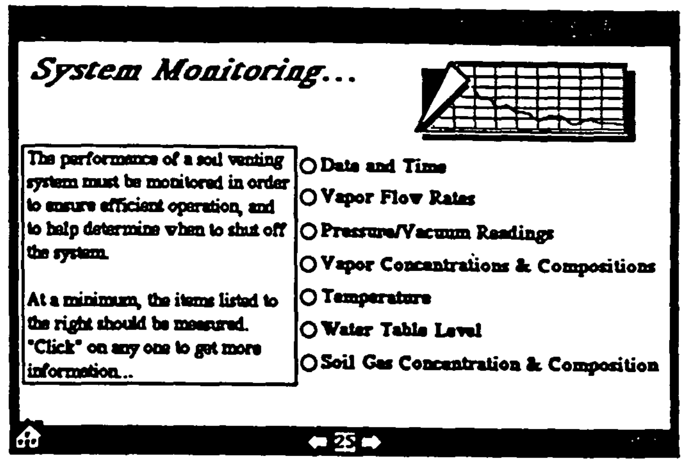

Field Tests
Paul & Dave's Venting Services
20

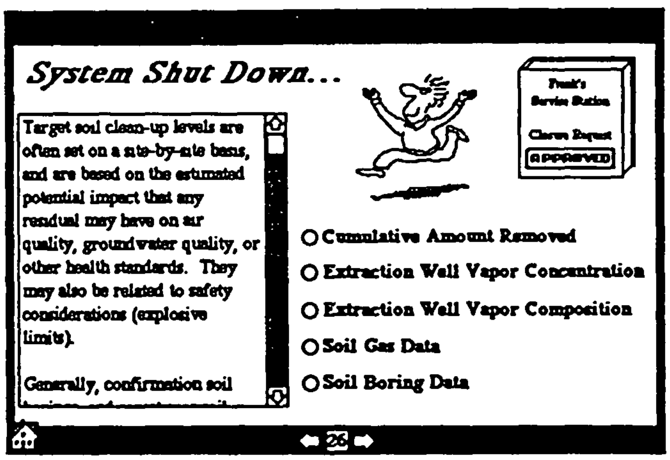

Field Tests
Prior to the design of an in situ soil venting system, it is desirable to obtain more refined estimates of the unsaturated zone permeability, potential vapor flowrates, and contaminant vapor concentrations. In addition, if a groundwater pumping system might be installed, then aquifer characteristics must also be determined.
Click on the buttons to the right to learn about these tests, or to analyze data that you have already collected.
Air Permeability Test
Aquifer Characterization
21

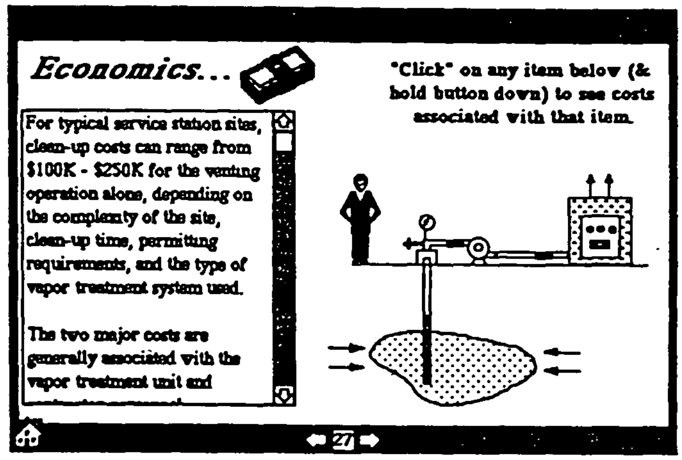

System Design
22

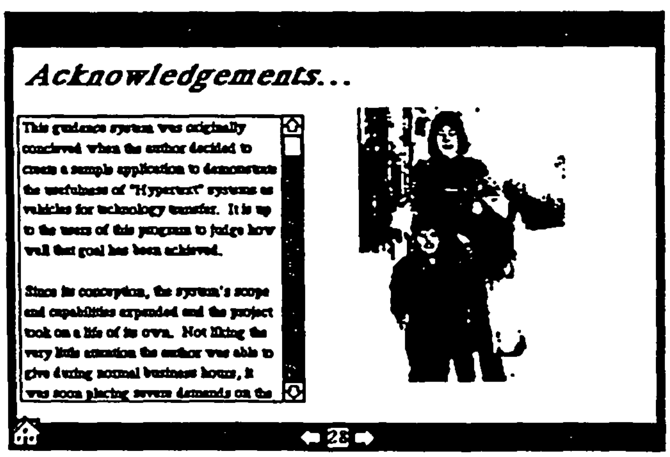

System Design...
For the system design process, you should assemble the following information:
• site plans (showing subsurface utilities, tanks, surface structures, etc.)
• plots of the subsurface (geologic cross-sections, water table maps, and soil boring and ground water sampling results)
• contaminant composition (or boiling point distribution)
• air permeability test data (permeability values & vapor concentrations)
• aquifer characteristics (ground water gradient, aquifer permeability, etc.)
Site Characterization Results
23


System Design...
At the right is a list of the components of a venting system design. Click on each to conduct the indicated phase of the design process
Remember: It is not our intention to provide a generic recipe for vacuum extraction system design; instead we suggest the following as a structured thought process. As you shall see, even in a structured thought process, intuition and experience play important roles. There is no substitute for a good fundamental understanding of vapor flow processes, transport phenomena, and ground water flow!
Number of Extraction Wells
Well Location
Well Construction
Surface Seals
Groundwater Pumping System
Vapor Treatment
24


System Monitoring...
The performance of a soil venting system must be monitored in order to ensure efficient operation, and to help determine when to shut off the system.
At a minimum, the items listed to the right should be measured. "Click" on any one to get more information...
Date and Time
Vapor Flow Rates
Pressure/Vacuum Readings
Vapor Concentrations & Compositions
Temperature
Water Table Level
Soil Gas Concentration & Composition
25


System Shut Down...
Frank's Service Station
Closure Request
APPROVED
Target soil clean-up levels are often set on a site-by-site basis, and are based on the estimated potential impact that any residual may have on air quality, groundwater quality, or other health standards. They may also be related to safety considerations (explosive limits).
Generally, confirmation soil
Cumulative Amount Removed
Extraction Well Vapor Concentration
Extraction Well Vapor Composition
Soil Gas Data
Soil Boring Data
26


Economics...
"Click" on any item below (& hold button down) to see costs associated with that item.
For typical service station sites, clean-up costs can range from $100K - $250K for the venting operation alone, depending on the complexity of the site, clean-up time, permitting requirements, and the type of vapor treatment system used.
The two major costs are generally associated with the vapor treatment unit and
27


Acknowledgements...
This guidance system was originally conceived when the author decided to create a sample application to demonstrate the usefulness of "Hypertext" systems as vehicles for technology transfer. It is up to the users of this program to judge how well that goal has been achieved.
Since its conception, the system's scope and capabilities expanded and the project took on a life of its own. Not liking the very little attention the author was able to give during normal business hours, it was soon placing severe demands on the
28

Appendix B: "Soil Venting Help Stack" stack cards.

Help: Stack Information

Buttons

Buttons have been placed in each card. Clicking on any button will perform an action, such as:

Go Home to first card in Venting Stack

Go to next card

Go to Help card

Print card or text field

Calculate — Perform a Calculation

When curious, click on Symbols, Pictures or Text.

Fields

Fields may contain information, or they may be a place for you to input numbers.

Scrolling Field:

Click on arrows to move text up or down

Click on the arrows, or move the box up or down with the mouse.

In this area, you can

Boxed Data Field:

When you see an I-beam cursor appear in a boxed field, click the mouse in the box to set the cursor. Then you may enter data.

A button will then usually be pushed to perform an action or calculation.

Try this example:

Enter Number in Box

1 inches

Click for calculation

2.54 centimeter

Return H1

Help: About Soil Venting

More information about soil venting can be found in the following articles:

M. C. Marley and G. E. Hoag, Induced Soil Venting for the Recovery/Restoration of Gasoline Hydrocarbons in the Vadose Zone, NWWA/API Conference on Petroleum Hydrocarbons and Organic Chemicals in Groundwater, Houston, TX, 1984.

P. C. Johnson, M. W. Kemblowski, and J. D. Colthart, Practical Screening Models for Soil Venting Applications, NWWA/API Conference on Petroleum Hydrocarbons and Organic Chemicals in Groundwater, Houston, TX, 1988.

N. J. Hutzler, B. E. Murphy, and J. S. Gierke, State of Technology Review: Soil Vapor Extraction Systems, U.S.E.P.A., CR-814319-01-1, 1988.

D. J. Wilson, A. N. Clarke, and J. H. Clarke, Soil Clean-up by in-situ Aeration. I. Mathematical Modelling, Sep. Science Tech., 23:991-1037, 1988.

H2 Return Print References

Help: In-Situ Soil Venting System Design Process

This is the decision process that one must follow to:

1) decide if soil venting is applicable at a given site

&

2) design an effective soil venting system

It is an abridged version of Figure 2 in "*A Practical Approach to the Design, Operation, & Monitoring of In-Situ Soil Venting Systems*", by P. C. Johnson, C. C. Stanley, M. W. Kemblowski, J. D. Colthart, and D. L. Byers.

Return H3

Help: Preliminary Site Investigation

More information about site investigation and remediation can be found in the following articles:

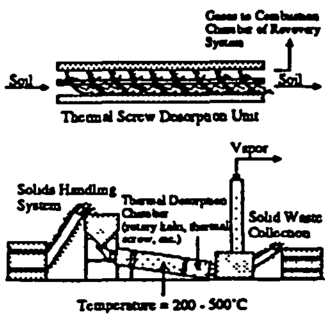
API Publication 1628
"A Guide to the Assessment and Remediation of Underground Petroleum Releases",
American Petroleum Institute, 1220 L Street Northwest, Washington DC, 20005

Return H4

Help: Thermal Desorption

Process Description

In a thermal desorption treatment process, soils contaminated with volatile/semi-volatile organics are heated, and the volatilized contaminants are stripped with air, steam, or combustion products (burner flue gases) at relatively modest temperatures compared with incineration (200-500°C versus 1000-1200°C). The desorbed organic contaminants are

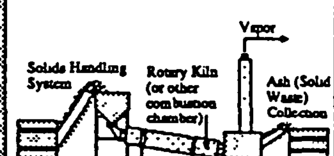


Return H5

Help: Incineration

Process Description

Incineration, or the thermal destruction of wastes, is a complete destruction technology that can be used to treat soils contaminated with a wide range of hazardous organic wastes. Contaminated soils, sludges, or liquid wastes are added to a high-temperature combustion chamber (rotary kiln, fixed hearth, multiple hearth, fluidized bed, liquid

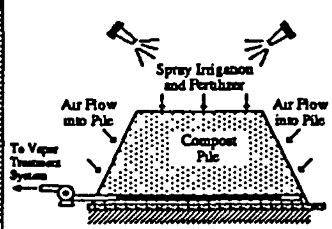


Return H6

Help: Composting

Process Description

Composting is an above-ground soil management technique in which amended soil, containing organic wastes, is placed in large piles and aerated. The aeration enhances microbial degradation by providing oxygen to the soil/waste. With time, the decomposed waste is reduced in weight and volume, and the process produces a stabilized, enriched, humus-like material,

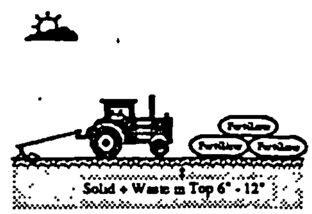


Return H7

Help: Land Farming

Process Description

"Landfarming" refers to the practice of spreading organic wastes over an area of land, then relying on natural microbial action to degrade the waste. It is a widely accepted and cost-effective practice for the treatment of petroleum hydrocarbons, chlorinated compounds, and pesticides. In this process soil-associated microorganisms (bacteria and



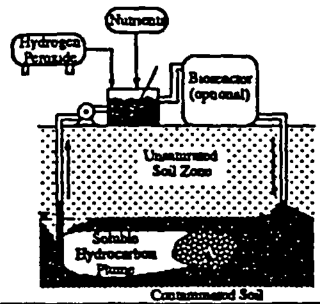
Return H8

Help: In-Situ Biostimulation

Process Description

Treatment of groundwater and soil contamination below the water table

("saturated zone") by in-situ biostimulation involves the addition of nutrients and/or O2 (usually as H2O2 or liquid O2) to an aquifer in order to enhance the degradation of the hydrocarbons by indigenous soil microbes. The nutrients and oxygen are added above ground to



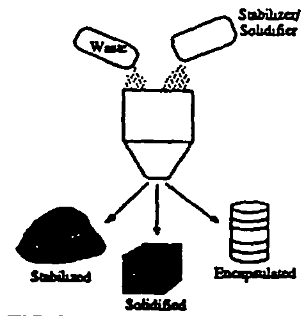
Return H9

Help: Solidification / Stabilization

Process Description

Stabilization and solidification are treatment processes designed to either improve waste handling and physical characteristics, decrease surface area across which pollutants can leach, or limit the solubility of hazardous constituents. When discussing this technology, the following definitions are common:

Solidification.

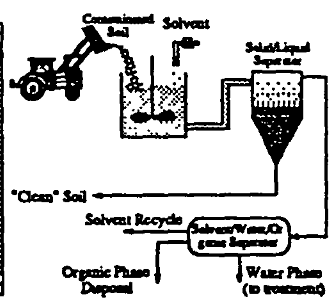


Return H10

Help: Solvent Extraction / Soil Washing

Process Description

"Solvent extraction" is the process by which contaminants are removed from soils or sludges by mixing them with a solvent into which the contaminants preferentially partition. Which solvent is used for any particular treatment is very dependent upon the type of contaminant present in the soil. The solvent should have a high affinity for the contaminant(s) of



Return H11

Help: Decision Matrix

● - applicable

⊖ - potentially applicable, but not conclusively demonstrated

(1) - Different compounds will vary in their degree of biodegradability. Larger compounds typically have slower degradation rates.

(2) - Free-liquid pumping is only applicable when the residual contamination level is so high that contaminants freely drain from the soil

	Biodegradation (1)	Encapsulation	Excavation	Incineration	Pumping (2) - product recovery	RF Heating/Venting (3)	In-Situ Soil Flushing (4)	Soil Washing/Extraction	Soil Venting	Solidification/Stabilization (5)	Thermal Desorption (6)	Vitrification
Aviation Fuel	●	●	●	●	●	●	⊖	●	⊖		●	●
Crude Oil	●	●	●	●	●	●	⊖	●			●	●
Gasoline	●	●	●	●	●	●	⊖	●	●		●	●
Lead		●	●				⊖	●		●		●
Metals, Salts		●	●				⊖	●		●		●
Petrochemicals	●	●	●	●	●	●	⊖	●	●	●	●	●
Pesticides	⊖	●	●	●		●	⊖	●			●	●
PCB's	⊖	●	●	●	●	●	⊖	●		⊖	●	●
Volatile Solvents	●	●	●	●	●	●	⊖	●	●		●	●

Return H12

Help: Soil Permeability

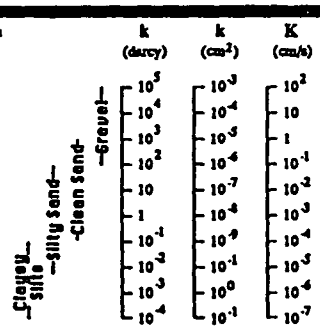
Note that k denotes the "permeability" of a porous media, while K represents the "hydraulic conductivity". The two are related by:

$$K = k\frac{\rho_{H_2O}g}{\mu_{H_2O}}$$

where:

g = acceleration due to gravity [980 cm/s²]
μ_{H_2O} = viscosity of water [0.01 g/cm-s]
ρ_{H_2O} = density of water [1.0 g/cm³]

When choosing permeability values it is important to keep in mind that k (or K) often varies by several orders of magnitude over small distances. For this



See Conversion Tables | Return to Flowrate Calculation | H13

Help: Vapor Flowrate per Unit Well Thickness

The equation below is the steady-state, one-dimensional, radial flow solution to a vertical well. While simplistic, it generally provides good estimates for vapor flowrates. Its accuracy is, of course, limited by the accuracy of the values you input. In particular, the greatest uncertainty is usually associated with the soil permeability, which can vary by several orders of magnitude over small distances.

$$\frac{Q}{H} = \pi\frac{k}{\mu}P_v\frac{[1 - (P_{Atm}/P_v)^2]}{\ln(R_v/R_I)}$$

k = soil permeability to air flow [cm²] or [darcy]
μ = viscosity of air = 1.8×10^{-4} g/cm-s or 0.018 cp
P_v = absolute pressure at extraction well [g/cm-s²] or [atm]
P_{Atm} = absolute ambient pressure = 1.01×10^6 g/cm-s² or 1 atm
R_v = radius of vapor extraction well [cm]
R_I = radius of influence of vapor extraction well [cm]
H = thickness of well screen interval, or permeable soil zone (choose smallest value)

Return H14

Help: Unit Conversion (k and K)

1) Enter value of hydraulic conductivity or permeability to be converted
2) Choose initial units
3) Choose final units - (click for each calculation)

1 cm² = 9.78374 x 10^4 cm/s

Convert From	Convert To
○ cm/s	◉ cm/s
○ ft/d	○ ft/d
◉ cm²	○ cm²
○ darcy	○ darcy

Return H15

H16

Help: Compound List

'Weathered' Gasoline

View Only Mode

	Compound Name	Mass Fraction	Molecular Weight (g)	Vapor Pressure @ 20 °C
1	propane	0.00	44.1	8.5
2	isobutane	0.00	58.1	2.93
3	n-butane	0	58.1	2.11
4	trans-2-butene	0	56.1	1.97
5	cis-2-butene	0	56.1	1.79
6	3-methyl-1-butene	0	70.1	0.96
7	isopentane	0.0069	72.2	0.78
8	1-pentene	0.0005	70.1	0.7
9	2-methyl-1-butene	0.0008	70.1	0.67
10	2-methyl-1,3-butadiene	0.0000	68.1	0.65

1.00000 = Sum of Mass Fractions (should be =1)

How Do I Measure a Distribution? | Return to Vapor Conc. Estimation Card | Print Lists

Summary Card: Site Characterization

A complete site assessment must determine the following:

Subsurface Characteristics

- soil stratigraphy
- characteristics of distinct soil layers (permeability estimates, soil types)
- depth to groundwater
- groundwater gradient
- seasonal water table fluctuations
- aquifer permeability (estimate)
- subsurface & above-ground temperatures

Contaminant Delineation

- extent of free-phase hydrocarbon
- distribution of contaminant in vadose zone
- distribution of contaminant in saturated zone
- extent of soluble contaminant plume
- composition of contaminant
- soil vapor concentrations (optional)

For more info see: API Publication 1628
"A Guide to the Assessment and Remediation of Underground Petroleum Releases",
American Petroleum Institute, 1220 L Street Northwest, Washington DC, 20005

Print Card

Return H17

Compound List Default Data

#	Compound Name	Molecular Weight (gm)	Boiling Point (°C) @ 1 Atm	Vapor Pressure (Atm) @T=20 °C	New Vapor Pressure (Atm) @T= 20 °C	Mass Fraction Data: All to	"Fresh" Gasoline	"Weathered" Gasoline
1	propane	44.1	-42	8.5	8.5	0.00	0.0001	0.00
2	isobutane	58.1	-12	2.93	2.93	0.00	0.0122	0.00
3	n-butane	58.1	-1	2.11	2.11	0.00	0.0629	0
4	trans-2-butene	56.1	1	1.97	1.97	0.00	0.0007	0
5	cis-2-butene	56.1	4	1.79	1.79	0.00	0.0000	0
6	3-methyl-1-butene	70.1	21	0.96	0.96	0.00	0.0006	0
7	isopentane	72.2	28	0.78	0.78	0.00	0.1049	0.0069
8	1-pentene	70.1	30	0.7	0.7	0.00	0.0000	0.0005
9	2-methyl-1-butene	70.1	31	0.67	0.67	0.00	0.0000	0.0008
10	2-methyl-1,3-butadiene	68.1	34	0.65	0.65	0.00	0.0000	0.0000

Return Print Lists H18

Help: Data for Fortran Program

#	Compound Name	Molecular Weight (gm)	Boiling Point (°C) @ 1 Atm	Vapor Pressure (Atm) @T= 20 °C	Solubility	Organic Carbon Dist. Coeff	Mass Fraction Dist.
1	propane	44.1	-42	8.5	62	73	0.00
2	isobutane	58.1	-12	2.93	49	537	0.00
3	n-butane	58.1	-1	2.11	61	946	0
4	trans-2-butene	56.1	1	1.97	430	204	0
5	cis-2-butene	56.1	4	1.79	430	204	0
6	3-methyl-1-butene	70.1	21	0.96	130	708	0
7	isopentane	72.2	28	0.78	48	1862	0.0069
8	1-pentene	70.1	30	0.7	148	710	0.0005
9	2-methyl-1-butene	70.1·	31	0.67	155	525	0.0008
10	2-methyl-1,3-butadiene	68.1	34	0.65	642	323	0.0000

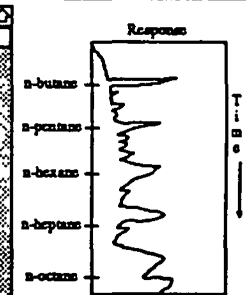
Return H19

H20

Help: How Do I Measure a Distribution?

Determining the exact composition of complex mixtures (such as gasoline) requires specialized analytical techniques. For the purpose of estimating the response to venting, however, an approximate composition can be used with very good results.

To determine an approximate distribution, one must analyze the mixture by gas chromatographic analyses. Prior to the analyses, choose about 6 - 10 marker compounds whose properties are well known. Often a series of straight chain alkanes (n-butane, n-pentane, n-hexane, etc.) is chosen. Then the unknown mixture is analyzed, and the areas of all peaks eluting between the retention times of two known peaks are summed and treated as one of the known peaks, as illustrated on the



Return to Vapor Conc. Calc. Calculate a Distribution

H21

Help: Calculate a Distribution

(1) Perform a GC analyses and sum all peaks whose retention times lie between the known compounds.

(2) Enter the areas or concentrations in the appropriate location in the Table on the right. Then, Click Calculate.

(3) Click the "Transfer Data..." button and your distribution will be copied to the Composition Table.

#	Compound	Concentration or Area	Normalized Distribution
1	propane	0.00	0.00000
2	n-butane	1000	0.07692
3	n-pentane	5000	0.38462
4	n-hexane	7000	0.53846
5	n-heptane	0.00	0.00000
6	n-octane	0.00	0.00000
7	n-nonane	0.00	0.00000
8	n-decane	0.00	0.00000
9	n-undecane	0.00	0.00000
10	n-dodecane	0.00	0.00000

Reset Calculate

Return to Vapor Conc. Calc. Card Return Transfer Data to Distribution Card

Help: About Calculation

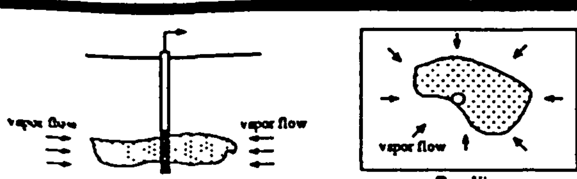
In this estimation of equilibrium (saturated) vapor concentrations, we assume that the contaminant concentrations are great enough (>200 mg/kg TPH) that it is distributed between vapor, sorbed, dissolved-in-soil-moisture, & free-phases. In this case, the equation at the right applies (look for "Raoult's Law" & the "Ideal Gas Law" in any thermodynamics textbook for references). We do correct for

$$C^v = \sum_{i=1}^{i=n} \frac{x_i P_i^v M_{w,i}}{RT}$$

C^v = total vapor concentration [mg/l]
n = number of components
x = mole fraction of component i
P^v = vapor pressure of component i [atm]
M_w = molecular weight of component i [mg/mole]
R = Universal Gas Constant = 0.0821 l-atm/K-mole
T = absolute temperature [K] = T(C) + 273

Return H22

Help: 6a) Dilution Effects [Bypassing]

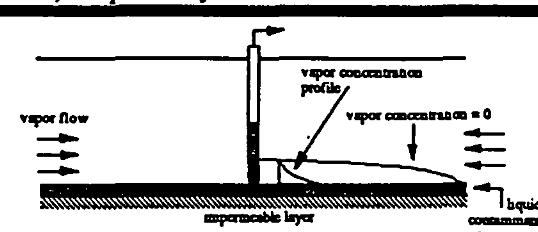


The figure above depicts the case where some vapors "bypass" zones of contamination, and therefore the vapors removed from the extraction well represent a mixture of the vapors obtained from both contaminated and clean vapor flowpaths. One can roughly judge the amount of bypassing by the well placement, screening, and contaminant distribution. Generally, observed vapor concentrations are roughly 10 - 50% of the ideal saturated

Return H23

H24

Help: 6b) Liquid Layers

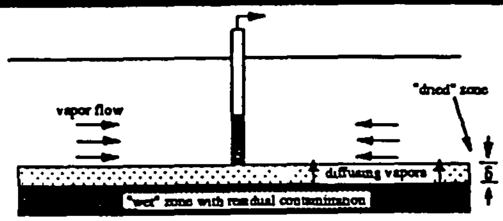


In Figure 6b, vapor flows parallel to, but not through, the zone of contamination, and the significant mass transfer resistance is vapor phase diffusion. This would be the case for a layer of liquid hydrocarbon resting on top of an impermeable strata or the water table. This problem was studied by Johnson et al (1988 - NWWA/API Petroleum Hydrocarbons Conference) for

Show Me Equations Return Let's Do a Calculation

H25

Help: 6c) Low Permeability Lenses



In the situation depicted above, vapor flows past, rather than through the contaminated soil zone, such as might be the case for a contaminated clay lens surrounded by sandy soils. In this case vapor diffusion through the clay to the flowing vapor limits the removal rate (the removal rate actually becomes

Show Me Equations | Return | Let's Do a Calculation

Help: 6c) Low Permeability Lenses - Equations

$$R_{est} = \pi (R_2^2 - R_1^2) \sqrt{\frac{C_{est} D^{eff} C_{soil} \rho_{soil}}{2t}} \qquad \delta = \sqrt{\frac{C_{est} D^{eff} t}{C_{soil} \rho_{soil}}}$$

where:

R_{est} = estimated removal rate [mg/d]
δ = thickness of "dried-out" zone [m]
R_1 = defines region in which contamination is present [m]
R_2 = defines region in which contamination is present [m]
C_{est} = estimated saturated vapor concentration [mg/m3]
D^{eff} = effective soil vapor diffusion coefficient [m2/d]
C_{soil} = initial residual level of contaminant in soil [mg/kg]
ρ_{soil} = soil bulk density [kg/m3]
t = time [d]

Derivations for these equations are given in Johnson, et al - "A Practical Approach to the Design, Operation and Monitoring of In Situ Soil Venting Systems" - 1990.

These Equations are valid for single-component

Let's Do a Calculation | Return | H26

Help: Default Boiling Point Ranges

The Fortran program HYPEVENT will report residual levels of compounds falling between user specified boiling point ranges. The default values have been chosen so that residual levels of compounds with boiling points between the following compounds are grouped together:

Propane - Isopentane (-50 to 28 C)
Isopentane - Benzene (28 to 80 C)
Benzene - Toluene (80 - 111 C)
Toluene - Xylenes (111 - 144 C)
Xylenes - Methylnapthalene (144 - 250 C)

Return | H27

Help: Boundary Layer Equations

$$R_{est} = \eta Q C_{est}$$
$$\eta = \frac{1}{3H} (6D^{eff}\mu/k)^{1/2} [\ln(R_I/R_w)/(P_{Atm} - P_w)]^{1/2} \sqrt{R_2^2 - R_1^2}$$

The equation above estimates the removal rate from a layer of liquid product by a single well, based on a Boundary Layer Theory approach to the problem. It is not directly applicable to mixtures, because it

R_{est} = estimated removal rate
η = efficiency relative to maximum removal rate
D^{eff} = effective soil vapor diffusion coefficient [cm2/s]
μ = viscosity of air = 1.8 x 10-4 g/cm-s
k = soil permeability to vapor flow [cm2]
H = thickness of screened interval [cm]
R_I = radius of influence of venting well [cm]
R_w = venting well radius [cm]
P_{Atm} = absolute ambient pressure = 1.016 x 106 g/cm-s2
P_w = absolute pressure at the venting well [g/cm-s2]
$R_1<r<R_2$ = defines region in which contamination is present

Let's Do a Calculation | Return | H28

Help: Boundary Layer Equations - Calculation

(1) Soil Type (choose one)

- ○ Medium Sand
- ○ Clayey Silts
- ○ Silty Sand
- ◉ Fine Sand
- ○ Input Your Own Permeability Range

[1] to [10] [darcys]

(2) Process Variables:

- [6.6] thickness of screened interval [ft]
- [40] radius of influence of venting well [ft]
- [2] venting well radius [in]
- [120] applied vacuum at well [in H2O]
- [40] radial width of contaminated zone

(3) --> Calculate <--

Just enter values into the appropriate fields, then click on the "calculate" button.

The "Relative Efficiency" is the ratio of the predicted removal rate to the removal rate that would be obtained if the extracted vapors were saturated, or in equilibrium with the liquid

Relative Efficiency (%) = [7.457548] to [23.582837]

Return | H29

Help: Low Permeability Lenses - Calculation

(1) Process Variables:
(input values)

- [4] venting well radius [in]
- [150] radial width of contaminated zone [ft]
- [10000] residual contaminant level [mg/kg]

(2) Contaminant Properties:

- [84.2420] contaminant molecular weight [g/mole]
- [43.9584] contaminant vapor pressure [mm Hg]
- [18] temperature (C)
- ○ use values already input from Card 10

Just enter values into the appropriate fields, then click on the "Calculate" button.

(3) --> Calculate <--

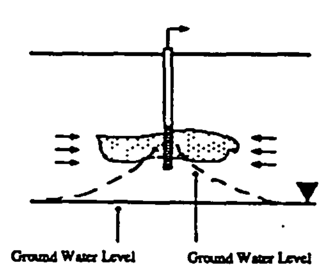
Time (days)	Removal Rate (kg/d)	δ (m)
1	3263.553	0.062
7	1233.507	0.164
30	595.841	0.340
60	421.323	0.481
120	297.920	0.681
180	243.251	0.834
240	210.661	0.963
360	172.004	1.179
540	140.441	1.444
720	121.625	1.668
1080	99.307	2.043

Return | H30

Ground Water Table Upwelling

During venting, the pressure within the radius of influence of the vapor extraction well is lowered, due to the applied vacuum. This lowering of the pressure affects the groundwater level in this zone, and an "upwelling", or local rise in the water table will occur.

The local water table rise can be as great as the gauge vacuum applied at the extraction well



Return | H31

Date and Time...

Generally, the DATE and TIME should be recorded along with any measurement that is made. Given the time scale for venting-related processes, recording the time to the nearest minute should be sufficient.

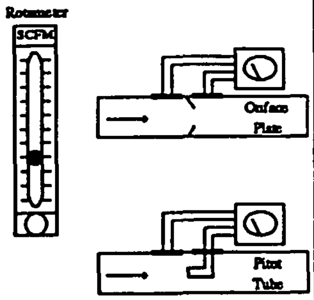
Sample devices are Rolex watches, hour glasses, sun dials, and timers.

Return | H32

Vapor Flow Rates...

Vapor flow rates from each extraction well and into any injection wells should be monitored.

Sample measuring devices include pitot tubes, orifice plates and rotameters. It is important to have calibrated these devices at the field operating pressures and temperatures

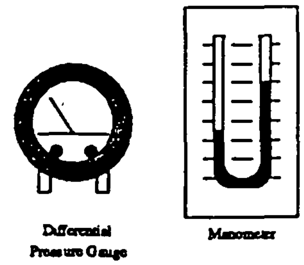


Return H33

Pressure/Vacuum Readings...

Pressures/Vacuums should be measured at each extraction and injection well. In addition, subsurface pressure distributions (measured with vadose zone installations) are useful for determining the zone of influence and vapor flow paths.

Typical pressure/vacuum measuring devices include manometers and differential pressure gauges.

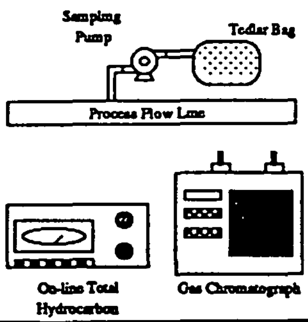


Return H34

Vapor Concentrations & Composition...

The vapor concentration and composition from each extraction well should be analyzed periodically. This data is multiplied by the extraction well flowrate to calculate the removal rate (i.e. lb/day), and cumulative amount of contaminant removed.

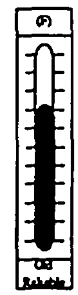
By itself, vapor concentration data does not give a complete picture of the system's performance. Decreases



Return H35

Temperature...

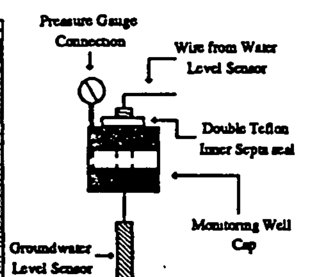
The soil and ambient temperatures can have a significant effect on the performance of soil venting systems. The soil temperature affects the contaminant vapor concentrations, while the ambient temperature controls whether or not condensation, or even freezing will be significant. For future reference, therefore, it is useful to record the ambient and soil temperatures.



Return H36

Water Table Level. (for contaminated soils located near the water table)

Whenever the contaminated zone lies near the groundwater table (within 3 to 5 ft), it is important to monitor the water table level to ensure that contaminated soils remain exposed to vapor flow. Measuring the water table level during venting is not a trivial task because the monitoring well must remain sealed. Uncapping the well releases the vacuum and any effect that it has on the water table level.

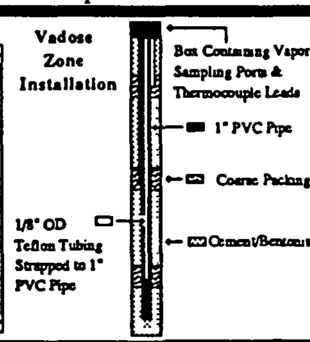


Return H37

Soil Gas Concentration & Composition...

These should be measured periodically at different radial distances from the vapor extraction well(s). Data from soil gas sampling is valuable for three reasons:

(1) by comparing extraction well concentrations with soil gas concentrations, it is possible to estimate the fraction of vapor that is flowing through the contaminated zone (i.e. the "efficiency" of

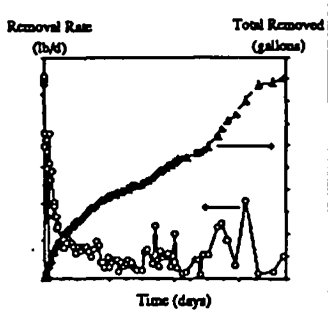


Return H38

Cumulative Amount Removed...

CUMULATIVE AMOUNT REMOVED

is determined by integrating the measured removal rates (flowrate x concentration) with time. While this value indicates how much contaminant has been removed, it is usually not very useful for determining when to take confirmation borings unless the original spill mass is known very accurately. In most cases that

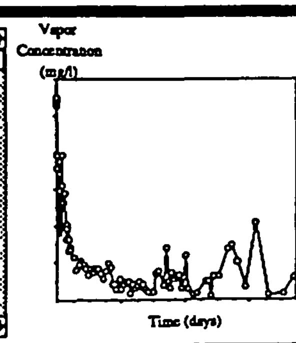


Return H39

Extraction Well Vapor Concentration...

EXTRACTION WELL VAPOR CONCENTRATION

the vapor concentrations are good indications of how effectively the venting system is working, but decreases in vapor extraction well concentrations are not strong evidence that soil concentrations have decreased. Decreases may also be due to other phenomena such as water table level increases, increased mass transfer resistance

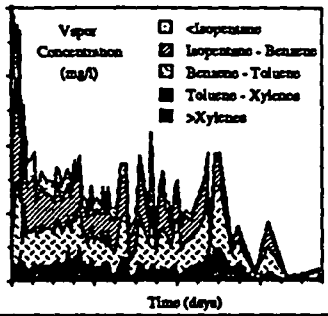


Return H40

Extraction Well Vapor Composition...

EXTRACTION WELL VAPOR COMPOSITION

when combined with vapor concentrations this data gives more insight into the effectiveness of the system. If the total vapor concentration decreases without a change in composition, it is probably due to increased mass transfer resistance (water table upwelling, drying-out of low permeability zones, etc.), and is not



Return H41

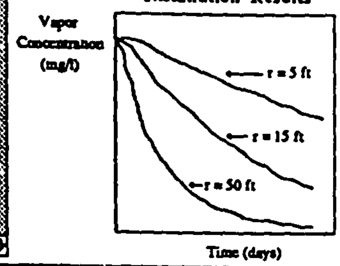
Soil Gas Data...

SOIL GAS DATA

this data is the most useful because it yields information about the residual composition and extent of contamination.

Vapor concentrations can not, in general, be used to determine the residual level, except in the limit of very low residual levels (when vapor concentrations are proportional to soil residual levels).

Soil Gas Monitoring Installation Results



Return H42

Soil Boring Data...

SOIL BORING DATA

Generally confirmation soil borings are taken once a system is turned off, and these are often analyzed for TPH (total petroleum hydrocarbons) and volatile residuals.

One should keep in mind that TPH results can often be misleading, since they reveal nothing about the composition of the residual or its

Soil Boring Results

Boring Location	TPH [mg/kg]	BTEX [mg/kg]
Before		
B-1	1200	20
B-2	14000	120
B-3	8600	400
After		
B-4	20	ND
B-5	120	0.1
B-6	5	ND

Return H43

Appendix C: "Air Permeability Test" stack cards.

Air Permeability Tests...

The purpose of an air permeability test is to obtain site-specific data that will be used in the final system design. It is a way to verify that venting is an appropriate remediation technique for your site.

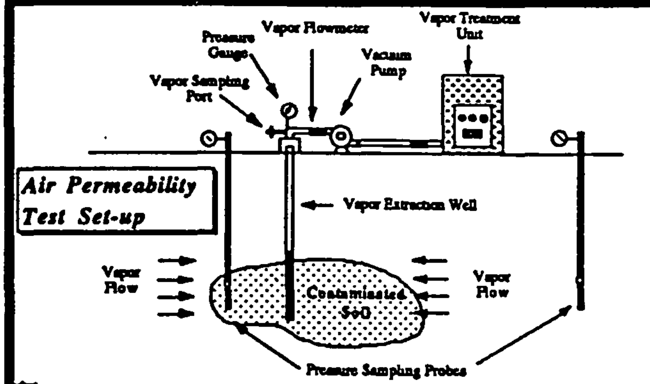
In particular, one typically tries to get a better estimate of the soil permeability of each distinct soil layer to be treated, and a better estimate of contaminant vapor concentrations

Show Me Set-Up

Test Instructions

Data Analysis

Return to Main Stack - Card 21 | AP1



Print Card | Return | AP2

Air Permeability Test - Instructions

1)
Identify soil zones to be treated

2)
Install vapor extraction well(s) in this zone(s). Existing monitoring wells may be used, when the screen interval extends only into the zone to be treated. Note the extraction well radius and borehole size. Insure that the well is not "connected" to other soil zones through the borehole (use cement/grout to seal annular borehole

show me sample data

Pore Volume Estimation:

Enter:
1) Soil Layer Thickness (ft): 6.6
2) Estimated Radius of Influence (ft): 50
3) Air Perm. Test Flowrate (CFM): 15

--> Calculate <--

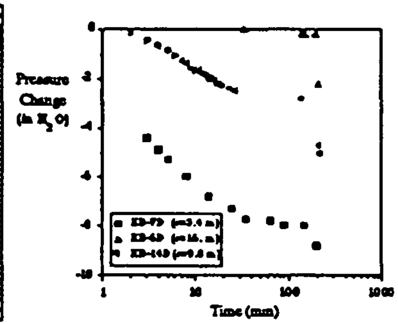
Pore Volume: 15543 ft**3
Time to Extract a Pore Volume: 0.72 days

Return | AP3

Air Permeability Test - Sample Data

Pictured at the right are the soil vacuum measurements from an air permeability test conducted in a silty sand.

The specific operating conditions and site characteristics are described in "A Practical Approach to the Design, Operation, and Monitoring of In Situ Soil Venting Systems", by P. C.



Return | AP4

Air Permeability Test - Data Analysis

The expected decrease in subsurface pressure (increase in gauge vacuum) P' is predicted by: (see Johnson et al (1990) for derivation)

$$P'(r,t) = \frac{Q}{4\pi m(k/\mu)} \int_{\frac{r^2 \varepsilon \mu}{4 k P_{Atm} t}}^{\infty} \frac{e^{-x}}{x}\, dx$$

P'	= gauge vacuum	ε	= air-filled void fraction
m	= stratum thickness	t	= time
r	= radial distance from extraction well	Q	= volumetric flowrate from extraction well
k	= soil permeability	P_{Atm}	= ambient atmospheric pressure
μ	= air viscosity = 0.018 centipoise		

Skip the Explanation | Return | AP5

Air Permeability Test - Data Analysis (cont.)

For $(r^2 \varepsilon \mu / 4 k P_{Atm} t) < 0.1$, the governing equation can be approximated by the expression:

$$P' = \frac{Q}{4\pi m(k/\mu)}\left[-0.5772 - \ln\left(\frac{r^2 \varepsilon \mu}{4 k P_{Atm}}\right) + \ln(t)\right]$$

This Equation predicts that a plot of P' -vs- ln(t) should be a straight line with slope A and y-intercept B equal to:

$$A = \frac{Q}{4\pi m(k/\mu)} \qquad B = \frac{Q}{4\pi m(k/\mu)}\left[-0.5772 - \ln\left(\frac{r^2 \varepsilon \mu}{4 k P_{Atm}}\right)\right]$$

Return | AP6

Air Permeability Test - Data Analysis (cont.)

The permeability, k, can then be calculated by one of two methods:

1. The first is applicable when both Q (flowrate) and m (well screen interval) are known accurately. The calculated slope A is used:

$$k = \frac{Q\mu}{4 A \pi m}$$

2. The second approach is used whenever Q or m are not known with confidence. In this case, both the slope, A, and intercept, B, are used:

$$k = \frac{r^2 \varepsilon \mu}{4 P_{Atm}} \exp\left[0.5772 + \frac{B}{A}\right]$$

Return | AP7

Air Permeability Test - Data Analysis (cont.)

1. Enter radial distances of monitoring points → r= 53 (ft) | r= 32.4 (ft) | r= (ft)
2. Enter measured times and gauge vacuums
3. Enter (optional):
   a) flowrate 15 (SCFM)
   b) screened interval thickness 6.6 (ft)

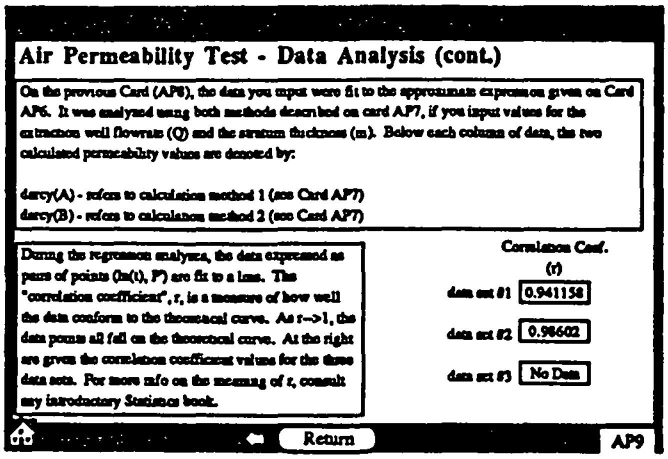
(min)	(in H_2O)	(min)	(in H_2O)	(min)	(in H_2O)
9	0.1	4	1.2		
11	0.2	7	3		
15	0.2	9	4.3		
23	0.4	12	5.5		
30	0.7	16	6.9		
40	1.3	24	9.9		
100	2.8	30	11		
		39	13		
		52	16		
		77	20		

clear | clear | clear

-->Calculate<--

k= 18.6948 darcy (A)	k= 2.85845 darcy (A)	k= darcy (A)
k= 9.29866 darcy (B)	k= 7.76759 darcy (B)	k= darcy (B)

Return | Explanation & Statistics | AP8

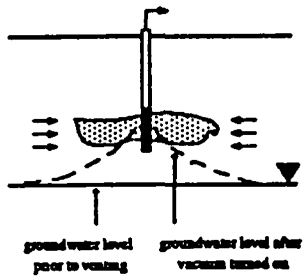

Air Permeability Test - Data Analysis (cont.)
On the previous Card (AP8), the data you input were fit to the approximate expression given on Card AP6. It was analyzed using both methods described on card AP7, if you input values for the extraction well flowrate (Q) and the stratum thickness (m). Below each column of data, the two calculated permeability values are denoted by:
darcy(A) - refers to calculation method 1 (see Card AP7)
darcy(B) - refers to calculation method 2 (see Card AP7)
During the regression analysis, the data expressed as pairs of points (ln(t), P') are fit to a line. The "correlation coefficient", r, is a measure of how well the data conform to the theoretical curve. As r->1, the data points all fall on the theoretical curve. At the right are given the correlation coefficient values for the three data sets. For more info on the meaning of r, consult any introductory Statistics book.
Correlation Coef.
(r)
data set #1
0.941158
data set #2
0.98602
data set #3
No Data
Return
AP9

Appendix D: "Aquifer Characterization" stack cards.

Aquifer Characterization:

To achieve efficient venting, the hydrocarbon-contaminated soil must be exposed to air flow, therefore, in most cases where the residual soil contamination lies close to, or below, the saturated soil zone (groundwater table), it will be necessary to incorporate a groundwater pumping system in the vapor extraction system design.

As mentioned previously, one must always be aware of the groundwater



Return to Main Stack

AC1

Aquifer Characterization:

Since most venting systems are installed above "phreatic aquifers" (aquifers with unconfined upper surfaces), the two primary aquifer parameters needed for design are:

K = hydraulic conductivity
S = effective porosity (or specific yield)

The first parameter represents a convenient combination of the fundamental parameters: permeability, density, and viscosity:

$$K = \frac{k \rho g}{\mu}$$

where:

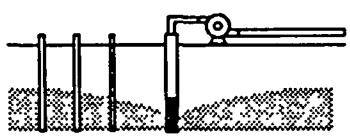
k = permeability
ρ = fluid density
g = acceleration due to gravity
μ = viscosity

Return to Main Stack

AC2

Aquifer Characterization:

These parameters (K and S) can be estimated using the results of a standard transient groundwater pump test with a constant pumping rate. The results are then compared against standard "type curves" for specific aquifer situations (i.e. leaky, unconfined aquifers, etc.).



Press the "References" button below for more information on slug tests, bail tests, pump tests, and data analysis.

References | Return to Main Stack

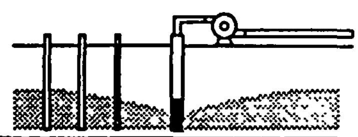
AC3

Aquifer Characterization - References

J. Bear, "Hydraulics of Groundwater", McGraw-Hill, 1979, ISBN 0-07-004170-9, p. 463 - 490.

R. A. Freeze and J. A. Cherry, "Groundwater", Prentice-Hall, 1979, ISBN 0-13-365312-9, p. 339 - 352.

G. R. Chirlin, "A Critique of the Hvorslev Method for Slug Test Analysis: The



Return

AC4

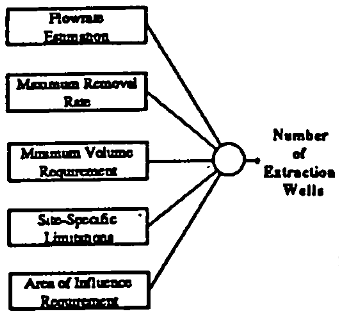
Appendix E: "System Design" stack cards.

Number of Venting Wells...

The procedure for estimating the required number of extraction wells is similar to the process used previously to determine if venting is appropriate at a given site.

As illustrated at the right, we will estimate single vertical well flowrates, calculate the minimum vapor flow required, determine the areal extent of influence, and then factor in any site-specific limitations. This information then determines the necessary number of extraction wells.

Just proceed to follow the steps dictated on the following cards—>



Return → SD1

Design Input,

(soil stratigraphy & contaminant characteristics)

Please enter the required information for each distinct soil layer, click on the "Update" button, and then proceed to the next card (i.e. click on right arrow at bottom).
(the tab key can be used to move between cells)

Select the total mass units that you prefer ◉ [kg] ○ [lb]

Clear All Entries

	Description of Soil Unit	Depth BGS* [ft]			Description of Contamination	Contaminant Distribution: radius [ft]	interval thickness [ft]	average conc [mg/kg]	Calc. Total Mass [kg]
1	Medium Sand	10	to	30	gasoline	20	20	100	120.9
2	Clayey Silt	30	to	43	gasoline	20	13	1000	786.0
3	Fine Sand	43	to	50	gasoline	20	7	10000	4232.3
4			to						0.0
5			to						0.0
6			to						0.0
7			to						0.0
8			to						0.0

* Below Ground Surface

Update

← Return → SD2

Design Input

Please enter the required information for each distinct soil layer, and then proceed to the next card.

Note: - click on any table heading to get more info
- use tab key to move between cells

○ Medium Sand ○ Fine Sand ○ Silty Sand ○ Clayey Silts

	Description of Soil Unit	Permeability* (darcy)			Design Vacuum (in H2O)	Extraction Well Construction: well radius [in]	screen thickness [ft]	radius of influence [ft]	Critical Volume of Air** [L/g]	Efficiency (%)
1	Medium Sand	10	to	100	40	2	10	40	128.48	100
2	Clayey Silt	0.01	to	.1	40	2	5	40	128	100
3	Fine Sand	1	to	10	40	2	5	40	128	100
4			to							
5			to							
6			to							
7			to							
8			to							

* Enter or choose from list at top right
** minimum volume of vapor required to achieve remediation

Clear All Entries ← Return → SD3

Design Input

Please enter (1) the desired time period for remediation, (2) the design gauge vacuum, and then (3) click the "update" button.

Note: - click on any table heading to get more info
- use tab key to move between cells

(3) Update

	Description of Soil Unit	(1) Time for Clean-up (days)	(2) Design Vacuum (in H2O)	Flowrate per Vapor Extraction Well [SCFM]			Minimum Number of Wells: Based on Area	Based on Critical Volume**		
1	Medium Sand	180	40	38.4	to	384.4	0.2	0.0	to	0.0
2	Clayey Silt	180	40	0.0	to	0.2	0.2	64.3	to	643.0
3	Fine Sand	180	40	1.9	to	19.2	0.2	3.5	to	34.6
4				NA	to	NA	NA	NA	to	NA
5				NA	to	NA	NA	NA	to	NA
6				NA	to	NA	NA	NA	to	NA
7				NA	to	NA	NA	NA	to	NA
8				NA	to	NA	NA	NA	to	NA

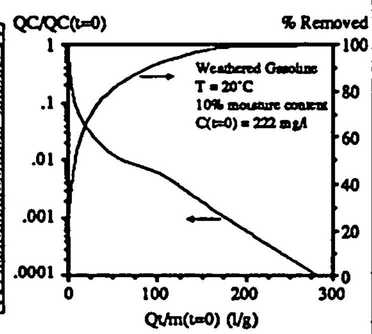
NA - not enough input data
** minimum volume of vapor required to achieve remediation

Clear All Entries ← Return SD4

Critical Volume Calculation...

Pictured at the right are the results of sample model predictions, for a weathered gasoline sample.

The vertical axis represents either normalized concentrations, or normalized removal rates, while the horizontal axis represents the total volume of vapor removed per initial mass of gasoline. Notice that the removal rate, and %removed curves resemble the behavior that is typically observed in venting operations.



Return to Design Do a Calculation SD5

Critical Volume Predictions...

Simply enter the temperature at the right, and then specify the composition of your contaminant. If you are unsure about this, click on the "About Composition..." button located at the lower right.

The model returns output that allows you to determine residual amounts of compounds falling within 5 boiling point ranges. Type in your own ranges, or choose the default values.

(1) Temperature (°C) 18

(2) Contaminant Composition (choose one) ○ Enter Distribution ○ "Fresh" Gasoline ◉ "Weathered" Gasoline

View Distributions

(3) --> Set Default BP Ranges <--

Boiling Point Range #1	-50	to	28	C
Boiling Point Range #2	28	to	80	C
Boiling Point Range #3	80	to	111	C
Boiling Point Range #4	111	to	144	C
Boiling Point Range #5	144	to	250	C

(4) Generate Predictions

tell me more about BP ranges... ← SD6 → About Composition...

(1) --> Import Data <--

FIRST PRESS THE IMPORT DATA BUTTON!

These are the results for the contaminant type that you have

Saturated Vapor Concentration at time=0 0.2053E+03 [mg/L]

Min Volume to Remove >90% of Initial Residual 128.48 [L-air/g-residual]

Temperature (°C): 18

Contaminant Type: Weathered Gasoline

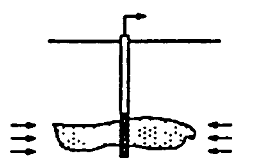
Qt/M(0) L-air/ g-residual	Vapor Conc. [% Initial]	Residual Level [% Initial]	BP #1 Residual [% total]	BP #2 Residual [% total]	BP #3 Residual [% total]	BP #4 Residual [% total]	BP #5 Residual [% total]
.00	100.000	100.000	.690	11.650	24.010	22.140	41.510
.24	75.062	95.000	.123	9.263	23.982	23.000	43.632
.57	58.631	90.022	.000	6.755	23.474	23.820	45.950
.98	48.078	85.034	.000	4.512	22.403	24.577	48.509
1.49	39.390	80.034	.000	2.632	20.771	25.248	51.350
2.11	31.941	75.035	.000	1.222	18.503	25.766	54.509
2.87	25.916	70.035	.000	.385	15.556	26.031	58.028
3.81	21.150	65.037	.000	.068	12.053	25.919	61.959

Launch Excel ← Return to System Design Print Card SD7

Removal Efficiency...

The subsurface is difficult to characterize, and rarely conforms to our notion of a "sandbox". There are three general classes of situations that will cause venting removal rates to be less than those predicted for the ideal case. Each of these are discussed in "A Practical Approach to the Design, Operation, and Monitoring of In Situ Soil Venting Systems". You can learn more about each by clicking on the buttons to the right.

In addition, when contaminants are located close to ground water, the effect of the vacuum on the water table level can significantly impact a venting system's performance. To learn about this, click on the "Ground Water Upwelling" button.



Dilution Effects

Liquid Layers

Low Permeability Lenses

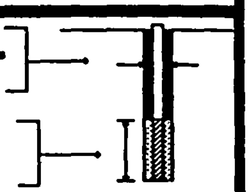
Ground Water Upwelling

Return SD8

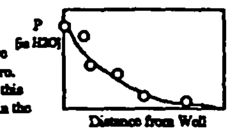
Help: Well Parameters

"Well Radius" - in general will be the radius of the well borehole, because the packing material is typically more permeable than the soil formation.

"Screen Thickness" is the length of the slotted interval of the well, or the thickness of the permeable zone, whichever is smaller.



"Radius of Influence" is the radial distance away from the extraction well, where the gauge pressure measured in the soil is approximately zero. The predictions are not very sensitive to this parameter, and most reported values lie in the range 40 - 120 ft.



Return to Design SD9

Help: Minimum Number of Wells

The "Minimum Number of Wells" is calculated by the two methods discussed below:

a) Based on Area -

In this approach we estimate the minimum number of wells required to provide air flow through the contaminated zone as you have defined it. If Rc denotes the radial extent of contamination, and Ri denotes the "radius of influence" of an extraction well, then:

$$N_{wells} = \frac{Rc^2}{Ri^2}$$

b) Based on Critical Volume of Vapor -

In this approach we determine the number of wells required to extract the critical volume of vapor from the contaminated soil zone within the desired time frame. In this approach:

$$N_{wells} = \frac{V_{critical}\, M_{spill}}{Q_{well}\, \epsilon\, \Delta T}$$

Vcritical = critical volume of vapor [L/g-residual]
Mspill = spill mass [g-residual]
Qwell = volumetric flowrate from single well [L/d]
ϵ = efficiency of extraction process
ΔT = time for clean-up [d]

Return to Design SD10

SD11

Contaminant Composition

Weathered Gasoline

View only Mode

	Compound Name	Mass Fraction	Molecular Weight (g)	Vapor Pressure @ 20 °C
1	propane	0.00	44.1	8.5
2	isobutane	0.00	58.1	2.93
3	n-butane	0.00	58.1	2.11
4	trans-2-butene	0.00	56.1	1.97
5	cis-2-butene	0.00	56.1	1.79
6	3-methyl-1-butene	0.00	70.1	0.96
7	isopentane	0.00	72.2	0.78
8	1-pentene	0.00	70.1	0.7
9	2-methyl-1-butene	0.00	70.1	0.67
10	2-methyl-1,3-butadiene	0.00	68.1	0.65

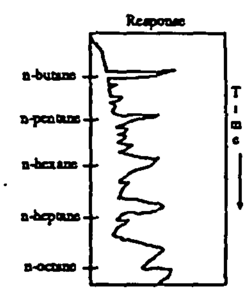
1.00000 = Sum of Mass Fractions

How Do I Measure a Distribution? Return to Critical Volume Pred. Print Lists

How Do I Measure a Distribution?

Determining the exact composition of complex mixtures (such as gasoline) requires specialized analytical techniques. For the purpose of estimating the response to venting, however, an approximate composition can be used with very good results.

To determine an approximate distribution, one must analyze the mixture by gas chromatographic analyses. Prior to the analyses, choose about 6 - 10 marker compounds whose properties are well known.



SD12 Calculate a Distribution

Calculate a Distribution

1. Perform a GC analyses and sum all peaks whose retention times lie between the known compounds.
2. Enter the areas or concentrations in the appropriate location in the Table on the right. Then, Click Calculate.
3. Click the "Transfer Data..." button and your distribution will be copied to the Composition Table.

#	Compound	Concentration or Area	Normalized Distribution
1	propane	0.00	0.00000
2	n-butane	0.00	0.00000
3	n-pentane	0.00	0.00000
4	n-hexane	1111	1.00000
5	n-heptane	0.00	0.00000
6	n-octane	0.00	0.00000
7	n-nonane	0.00	0.00000
8	n-decane	0.00	0.00000
9	n-undecane	0.00	0.00000
10	n-dodecane	0.00	0.00000

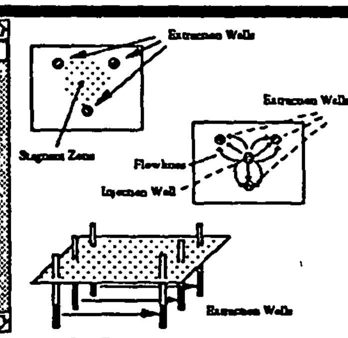
Reset Calculate

SD13 Return Transfer Data to Distribution Card

Well Location

To be able to successfully locate extraction wells, passive wells, and surface seals one must have a good understanding of vapor flow behavior. Wells locations should be chosen to maximize vapor flow through the contaminated zone, while minimizing vapor flow through other zones.

If one well is sufficient, it should almost always be placed in the geometric center of the

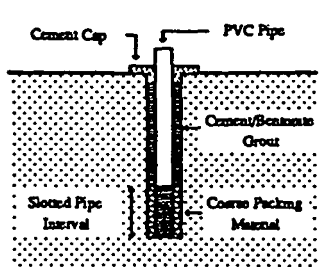


SD14 Return to Design

Well Construction

Wells should be screened only through the zone of contamination, unless the permeability to vapor flow is so low that removal rates would be greater if flow were induced in an adjacent soil layer. Removal rate estimates for various mass-transfer limited scenarios are discussed elsewhere in this stack.

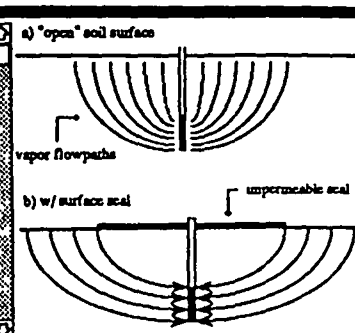
Based on predictive equations, the flowrate is expected to increase by 15% when the extraction well



SD15 Return to Design

Surface Seals

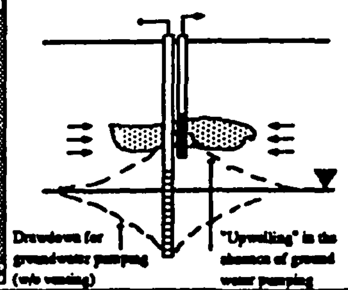
Surface seals, such as polymer-based liners and asphalt, concrete, or clay caps, are sometimes used to control the vapor flow paths. Figure 12 illustrates the effect that a surface seal will have on vapor flow patterns. For shallow treatment zones (<5 m) the surface seal will have a significant effect on the vapor flow paths, and seals can be added or removed to achieve the desired vapor flowpath. For



SD16 Return to Design

Groundwater Pumping Systems

In cases where contaminated soils lie just above or below the water table, groundwater pumping systems will be required to insure that contaminated soils remain exposed. In designing a groundwater system it is important to be aware that upwelling (draw-up) of the groundwater table will occur when a vacuum is applied at the extraction well (see the figure at the right).



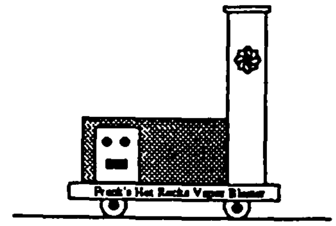
SD17 Return to Design

Vapor Treatment Systems

Currently there a four main treatment processes available:

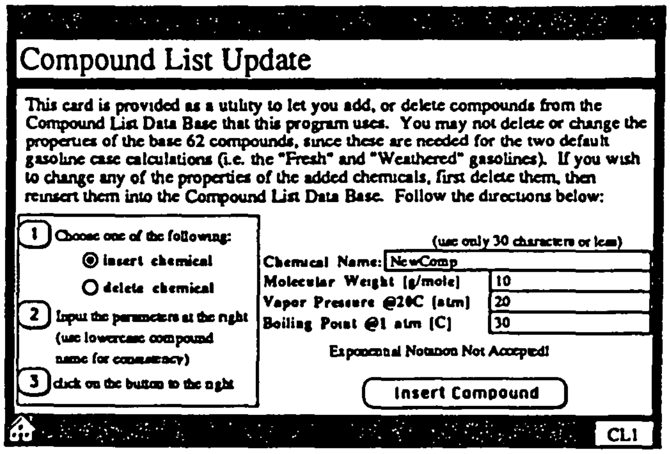
VAPOR COMBUSTION UNITS:

Vapors are incinerated and destruction efficiencies are typically >95%. A supplemental fuel, such as propane, is added before combustion unless extraction well vapor concentrations are on the order of



SD18 Return to Design

Appendix F: "Compound List Update" stack cards.


Compound List Update
This card is provided as a utility to let you add, or delete compounds from the Compound List Data Base that this program uses. You may not delete or change the properties of the base 62 compounds, since these are needed for the two default gasoline case calculations (i.e. the "Fresh" and "Weathered" gasolines). If you wish to change any of the properties of the added chemicals, first delete them, then reinsert them into the Compound List Data Base. Follow the directions below:
1 Choose one of the following:
insert chemical
delete chemical
2 Input the parameters at the right (use lowercase compound name for consistency)
3 click on the button to the right
(use only 30 characters or less)
Chemical Name: NewComp
Molecular Weight (g/mole) 10
Vapor Pressure @20C (atm) 20
Boiling Point @1 atm (C) 30
Exponential Notation Not Accepted!
Insert Compound
CL1

Appendix G: Reprint of:

"A Practical Approach to the Design, Operation, and Monitoring of In Situ Soil Venting Systems"

Reprinted from the Spring 1990 Issue of
Ground Water Monitoring Review

A Practical Approach to the Design, Operation, and Monitoring of In Situ Soil-Venting Systems

by P.C. Johnson, C.C. Stanley, M.W. Kemblowski, D.L. Byers, and J.D. Colthart

Abstract

When operated properly, in situ soil venting or vapor extraction can be one of the most cost-effective remediation processes for soils contaminated with gasoline, solvents, or other relatively volatile compounds. The components of soil-venting systems are typically off-the-shelf items, and the installation of wells and trenches can be done by reputable environmental firms. However, the design, operation, and monitoring of soil-venting systems are not trivial. In fact, choosing whether or not venting should be applied at a given site is a difficult decision in itself. If one decides to utilize venting, design criteria involving the number of wells, well spacing, well location, well construction, and vapor treatment systems must be addressed. A series of questions must be addressed to decide if venting is appropriate at a given site and to design cost-effective in situ soil-venting systems. This series of steps and questions forms a "decision tree" process. The development of this approach is an attempt to identify the limitations of in situ soil venting, and subjects or behavior that are currently difficult to quantify and for which future study is needed.

Introduction

When operated properly, in situ soil venting or vapor extraction can be a cost-effective remediation process for soils contaminated with gasoline, solvents, or other relatively volatile compounds. A "basic" system, such as the one shown in Figure 1, couples vapor extraction (recovery) wells with blowers or vacuum pumps to remove vapors from the vadose zone and thereby reduce residual levels of soil contaminants. More complex systems incorporate trenches, air injection wells, passive wells, and surface seals. Above-ground treatment systems condense, adsorb, or incinerate vapors; in some cases vapors are simply emitted to the atmosphere through diffuser stacks. In situ soil venting is an especially attractive treatment option because the soil is treated in place, sophisticated equipment is not required, and the cost is typically lower than other options.

The basic phenomena governing the performance of soil-venting systems are easily understood. By applying a vacuum and removing vapors from extraction wells, vapor flow through the unsaturated soil zone is induced. Contaminants volatilize from the soil matrix and are swept by the carrier gas flow (primarily air) to the extraction wells or trenches. Many complex processes occur on the microscale, however, the three main factors that control the performance of a venting operation are the chemical composition of the contaminant, vapor flow rates through the unsaturated zone, and the flow path of carrier vapors relative to the location of the contaminants.

The components of soil-venting systems are typically off-the-shelf items, and the installation of wells and trenches can be done by reputable environmental firms. However, the design, operation, and monitoring of soil-venting systems is not trivial. In fact, choosing whether or not venting should be applied at a given site is a difficult question in itself. If one decides to utilize venting, design criteria involving the number of wells, well spacing, well location, well construction, and vapor treatment systems must be addressed. It is the current state-of-the-art that such questions are answered more by experience than by rigorous logic. This is evidenced by published soil venting "success stories" (see Hutzler et al. 1988 for a good review), which rarely include insight into the design process.

In this paper, a series of questions are presented that must be addressed to:

- Decide if venting is appropriate at a given site.
- Design cost-effective in situ soil-venting systems.

This series of steps and questions forms a "decision tree" process. The development of this approach is an attempt to identify the limitations of in situ soil venting, and subjects or behavior that are currently difficult to quantify and for which future study is needed.

The "Practical Approach"

Figure 2 presents a flow chart of the process discussed in this paper. Each step of the flow chart will be discussed in detail, and where appropriate, examples are given.

The Site Characterization

Whenever a soil contamination problem is detected or suspected, a site investigation is conducted to characterize and delineate the zone of soil and ground water contamination. In general, the site characterization is conducted in two stages. The emergency response and abatement phase assesses the immediate impact on potential human and environmental receptors, and is conducted in a relatively short period of time (days). A detailed site characterization then follows. Its purpose, like the emergency response and abatement phase, is to determine potential migration pathways and assess the environmental impact associated with present conditions and future migration of the contaminants. Often the sequence of steps following initial response and abatement is as follows:

Background review: Involves assembling historical records, plot plans, engineering drawings (showing utility lines), and interviewing site personnel. This information is used to help identify the contaminant, probable source of release, zone of contamination, and potentially impacted areas (neighbors, drinking water supplies, etc.).

- **Preliminary site screening:** Preliminary screening tools such as soil-gas surveys and cone penetrometers are used to roughly define the zone of contamination and the site geology. Knowledge of site geology is essential to determine probable migration of contaminants through the unsaturated zone.

Detailed site characterization: Soil borings are drilled and monitoring wells are installed.

Contaminant characterization: Soil and ground water samples are analyzed to determine contaminant concentrations and compositions.

Costs associated with site investigations can be relatively high depending on the complexity of the site and size of the spill or leak. For large spills and complex site geological/hydrogeological conditions, site investigation costs may begin to approach remediation costs. In addition, the choice and design of a remediation system is based on the data obtained during the site investigation. For these reasons it is important to ensure that specific information is collected, and to validate the quality of the data.

If it is presumed that in situ soil venting will be a candidate for treatment, then the following information needs to be obtained during the preliminary site investigation:

Subsurface characteristics — site geology: This includes the determination of soil stratigraphy (vadose and saturated zone) and characteristics of distinct soil layers (i.e., soil type, permeability estimates). While they are not essential, the moisture content, total organic carbon, and permeability of each distinct soil layer also provides useful information that can be used to choose and design a remediation system.

Subsurface characteristics — site hydrogeology: Depth to ground water, and the ground water gradient must be known, as well as estimates of the aquifer hydraulic conductivity.

- **Contaminant delineation:** The distribution of contaminants in the saturated and vadose zones needs to be assessed. This includes the extent of the free-phase hydrocarbon, residual hydrocarbon, and solu-

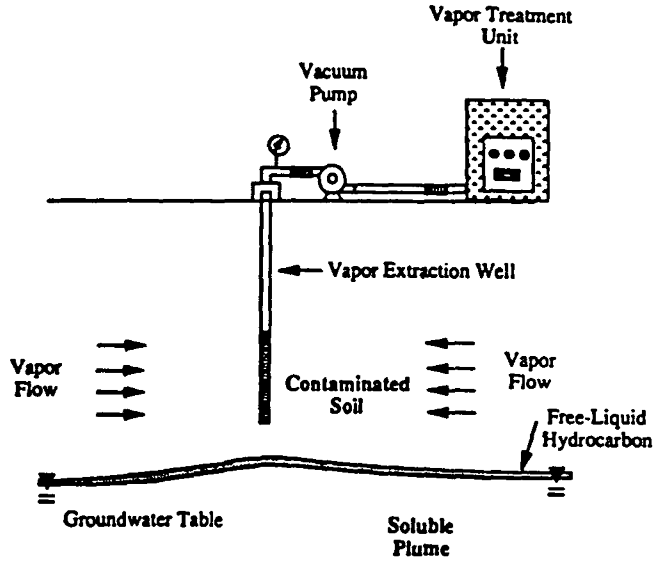


Figure 1. "Basic" in situ soil-venting system.

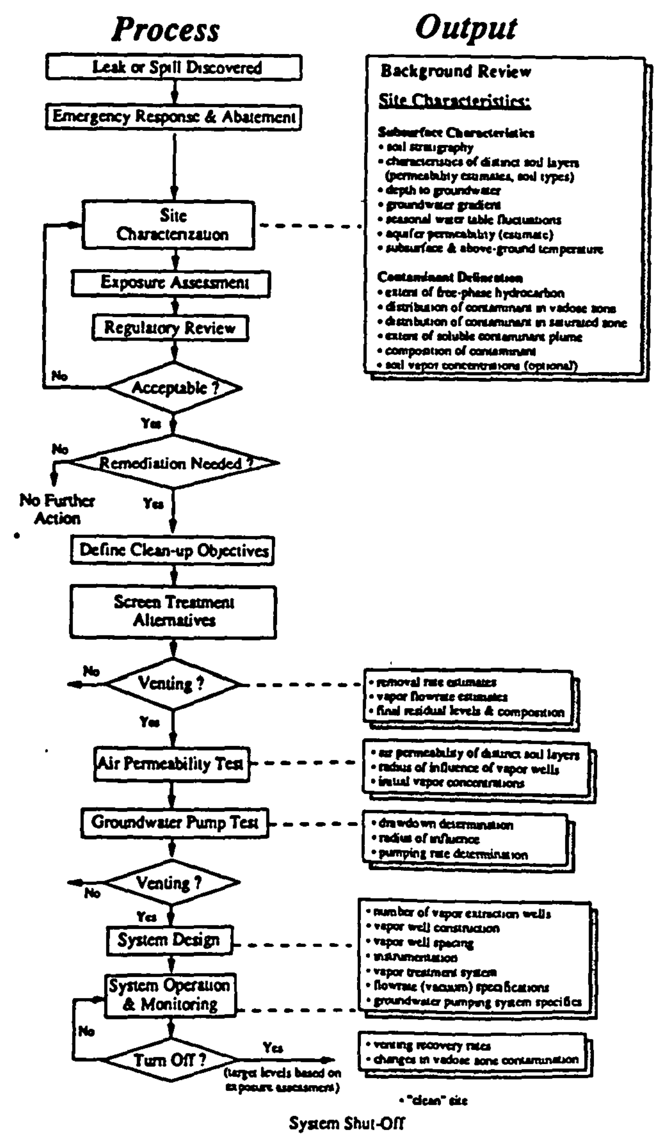


Figure 2. In situ soil-venting system design process.

ble hydrocarbon. Soil samples should be analyzed to determine which contaminants are present at what levels (contaminant composition). Specific analytical methods should be used to identify target compounds (i.e., benzene, toluene, or xylenes) and total hydrocarbons present. For soil analyses these methods are:

EPA 8240, 8020, 8010 - volatile organic chemicals (VOCs)
EPA 8270 - semivolatile organic chemicals
EPA 418.1 - total petroleum hydrocarbons (TPH).

The corresponding methods for water samples are:

EPA 8240, 8020, 8010 - volatile organic chemicals (VOCs)
EPA 8270 - semivolatile organic chemicals
EPA 418.1 - total petroleum hydrocarbons (TPH).

With the current high cost of chemical analyses it is important to intelligently select which analyses should be performed and which samples should be sent to a certified laboratory. Local regulations usually require that a minimum number of soil borings be performed, and target compounds must be analyzed based on the suspected composition of the contamination. Costs can be minimized and more data obtained by utilizing field screening tools, such as hand-held vapor meters or portable field gas chromatographs (GCs). These instruments can be used to measure both residual soil contamination levels and headspace vapors above contaminated soils. At a minimum, soil samples corresponding to lithology changes or obvious changes in residual levels (based on visual observations or odor) should be analyzed.

For complex contamination mixtures, such as gasoline, diesel fuel, and solvent mixtures, it is not practical or necessary to identify and quantify each compound present. In such cases it is recommended that a "boiling point" distribution be measured for a representative sample of the residual contamination. Boiling point distribution curves, such as shown in Figure 3 for "fresh" and "weathered" gasoline samples, can be constructed from GC analyses of the residual soil contamination (or free product) and knowledge of the GC elution behavior of a known series of compounds (such as straight-chain alkanes). Compounds generally elute from a GC packed column in the order of increasing boiling point, so a boiling point distribution curve is constructed by grouping all unknowns that elute between two known peaks (i.e., between n-hexane and n-heptane). Then they are assigned an average boiling point, molecular weight, and vapor pressure. Use of these data will be explained later.

The cone penetrometer, which is essentially an instrumented steel rod that is driven into the soil, is becoming a popular tool for preliminary site screening investigations. By measuring the shear and normal forces on the leading end of the rod, soil structure can be defined and permeability or hydraulic conductivity can be estimated. Some cone penetrometers are also constructed to allow the collection of vapor or ground water samples. This tool has several advantages over conventional soil boring techniques (as a preliminary site characterization tool): (1) the subsurface soil structure can be defined better; (2) no soil cuttings are generated; and (3) more analyses can be performed per day.

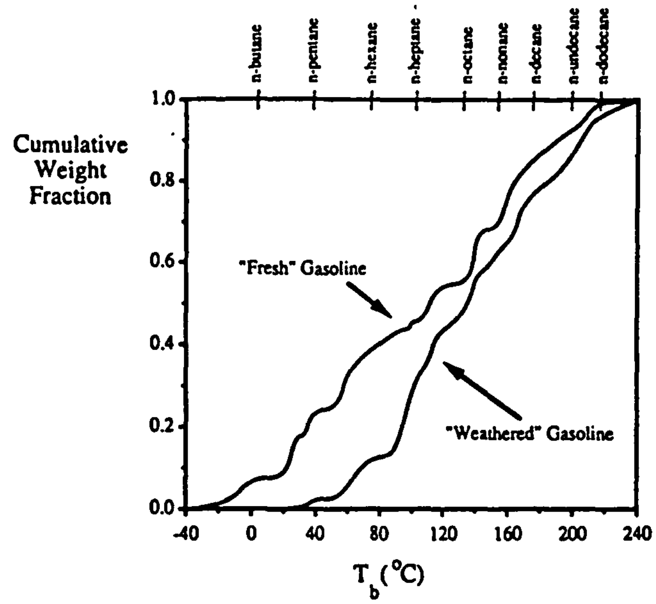


Figure 3. Boiling point distribution curves for samples of "fresh" and "weathered" gasolines.

- **Temperature** (both above and below ground surface) Contaminant vapor concentrations are dependent on temperature, and therefore, removal rates are strongly influenced by subsurface temperatures. Above-ground temperatures will influence the selection of materials and construction of the above-ground vapor treatment system.

Results from the preliminary site investigation should be summarized in contour plots, fence diagrams, and tables in preparation for deciding whether venting is appropriate, and for the final design of the system.

Deciding if Venting Is Appropriate

As previously stated, the three main factors governing the behavior of any in situ soil-venting operation are the vapor flow rate, contaminant vapor concentrations, and the vapor flow path relative to the contaminant location. In an article by Johnson et al. (1988), simple mathematical equations were presented to help quantify each of these factors. Following it is illustrated how to use these "screening models" and the information collected during the preliminary site investigation to help determine if in situ soil venting is appropriate at a given site. In making this decision the following questions will be answered:

1. What contaminant vapor concentrations are likely to be obtained?

2. Under ideal vapor flow conditions (i.e., 100 – 1000 scfm vapor flow rates), is this concentration great enough to yield acceptable removal rates?

3. What range of vapor flow rates can realistically be achieved?

4. Will the contaminant concentrations and realistic vapor flow rates produce acceptable removal rates?

5. What residual, if any, will be left in the soil? What

vapor composition and concentration changes will occur with time? How do these values relate to the regulatory requirements?

6. Are there likely to be any negative effects of soil venting?

Negative answers to questions 2 or 4 will rule out in situ soil venting as a practical treatment method.

What Contaminant Vapor Concentrations Are Likely to Be Obtained?

Question 1 can be answered based on the results of soil-vapor surveys, analyses of headspace vapors above contaminated soil samples, or equilibrium vapor models (Johnson et al. 1988). In some cases just knowing which compounds are present is sufficient to estimate if venting is feasible. In the absence of soil-vapor survey data, contaminant vapor concentrations can be estimated. The maximum vapor concentration of any compound (mixture) in extracted vapors is its equilibrium or "saturated" vapor concentration, which is easily calculated from knowledge of the compound's (mixture's) molecular weight, vapor pressure at the soil temperature, residual soil contaminant composition, and the ideal gas law:

$$C_{est} = \sum_i \frac{x_i P_i^v M_{w,i}}{RT} \qquad (1)$$

where:

C_{est} = estimate of contaminant vapor concentration [mg/L]

x_i = mole fraction of component i in liquid-phase residual ($x_i = 1$ for single compound)

P_i^v = pure component vapor pressure at temperature T [atm]

$M_{w,i}$ = molecular weight of component i [mg/mole]

R = gas constant = 0.0821 l-atm/mole-°K

T = absolute temperature of residual [°K].

Table 1 presents data for some chemicals and mix-

TABLE 1

Selected Compounds and Their Chemical Properties (Johnson et al. 1988)

Compound	M_w (g/mole)	T_b (1 atm) (C)	P_v° 20 C (atm)	C_{est} (mg/L)
n-pentane	72.2	36	0.57	1700
n-hexane	86.2	69	0.16	560
trichloroethane	133.4	75	0.132	720
benzene	78.1	80	0.10	320
cyclohexane	84.2	81	0.10	340
trichloroethylene	131.5	87	0.026	140
n-heptane	100.2	98	0.046	190
toluene	92.1	111	0.029	110
tetrachloroethylene	166	121	0.018	130
n-octane	114.2	126	0.014	65
chlorobenzene	113	132	0.012	55
p-xylene	106.2	138	0.0086	37
ethylbenzene	106.2	138	0.0092	40
m-xylene	106.2	139	0.0080	35
o-xylene	106.2	144	0.0066	29
styrene	104.1	145	0.0066	28
n-nonane	128.3	151	0.0042	22.0
n-propylbenzene	120.2	159	0.0033	16
1,2,4 trimethylbenzene	120.2	169	0.0019	9.3
n-decane	142.3	173	0.0013	7.6
DBCP	263	196	0.0011	11
n-undecane	156.3	196	0.0006	3.8
n-dodecane	170.3	216	0.00015	1.1
napthalene	128.2	218	0.00014	0.73
tetraethyllead	323	dec.@200C	0.0002	2.6
gasoline[1]	95	-	0.34	1300
weathered gasoline[2]	111	-	0.049	220

[1]Corresponds to "fresh" gasoline defined in Table 2 with boiling point distribution shown in Figure 3.

[2]Corresponds to "weathered" gasoline defined in Table 2 with boiling point distribution shown in Figure 3.

T_b (1 atm) - compound boiling point at 1 atm absolute pressure.

M_w - molecular weight.

C_{est} - equilibrium vapor concentration (see Equation 1).

P_v° (20 C), - vapor pressure measured at 20 C.

tures accidentally released to the environment. There are more sophisticated equations for predicting vapor concentrations in soil systems based on equilibrium partitioning arguments, but these require more detailed information (organic carbon content, soil moisture) than is normally available. If a site is chosen for remediation, the residual total hydrocarbons in soil typically exceed 500 mg/kg. In this residual concentration range most of the hydrocarbons will be present as a separate or "free" phase, the contaminant vapor concentrations become independent of residual concentration (but still depend on composition), and Equation 1 is applicable (Johnson et al. 1988). In any case, it should be noted that these are estimates only for vapor concentrations at the start of venting, which is when the removal rates are generally greatest. Contaminant concentrations in the extracted vapors will decline with time due to changes in composition, residual levels, or increased diffusional resistances. These topics will be discussed in more detail.

Under Ideal Vapor Flow Conditions (i.e., 100 – 1000 scfm Vapor Flow Rates), Is This Concentration Great Enough to Yield Acceptable Removal Rates?

Question 2 is answered by multiplying the concentration estimate C_{est}, by a range of reasonable flow rates, Q:

$$R_{est} = C_{est}\, Q \tag{2}$$

Here R_{est} denotes the estimated removal rate, and C_{est} and Q must be expressed in consistent units. For reference, documented venting operations at service station sites typically report vapor flow rates in the 10 – 100 scfm range (Hutzler et al. 1988), although 100 – 1000 scfm flow rates are achievable for sandy soils or large numbers of extraction wells. At this point in the decision process what is still being neglected is that vapor concentrations decrease during venting due to compositional changes and mass transfer resistances. Figure 4 presents calculated removal rates R_{est} [kg/d] for a range of C_{est} and Q values. C_{est} values are presented in [mg/L] and [ppm_{CH4}] units, where [ppm_{CH4}] represents methane-equivalent parts-per-million volume/volume (ppm_v) units. The [ppm_{CH4}] units are used because field analytical tools that report [ppm_v] values are often calibrated with methane. The [mg/L] and [ppm_{CH4}] units are related by:

$$[mg/L] = \frac{[ppm_{CH4}] * 16000 \text{ mg-}CH_4/\text{mole-}CH_4 * 10^{-6}}{(0.0821 \text{ l-atm/}^\circ\text{K-mole}) * (298 \text{ K})} \tag{3}$$

For field instruments calibrated with other compounds (i.e., butane, propane), [ppm_v] values are converted to [mg/L] by replacing the molecular weight of CH_4 in Equation 3 by the molecular weight [mg/mole] of the calibration compound.

Acceptable or desirable removal rates $R_{acceptable}$, can be determined by dividing the estimated spill mass M_{spill}, by the maximum acceptable cleanup time τ:

$$R_{acceptable} = M_{spill}/\tau \tag{4}$$

For example, if 1500kg (~ 500 gal) of gasoline had been spilled at a service station and it was wished to

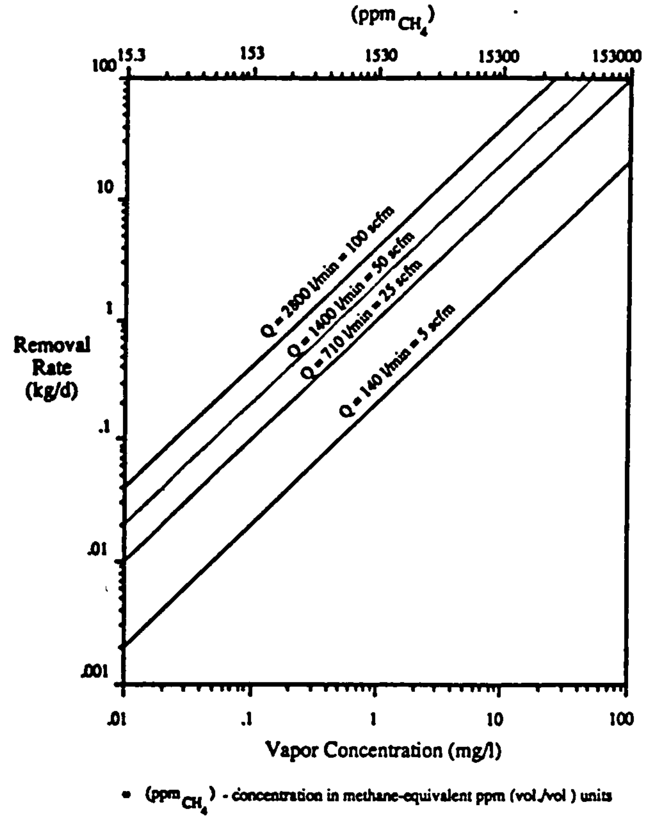


Figure 4. In situ soil-venting removal rate dependence on vapor extraction rate and vapor concentration.

complete the cleanup within eight months, then $R_{acceptable}$ = 6.3 kg/d. Based on Figure 4, therefore, C_{est} would have to average >1.5 mg/L (2400 ppm_{CH4}) for Q=2800 l/min (100 cfm) if venting is to be an acceptable option. Generally, removal rates <1 kg/d will be unacceptable for most releases, so soils contaminated with compounds (mixtures) having saturated vapor concentrations less than 0.3 mg/L (450 ppm_{CH4}) will not be good candidates for venting, unless vapor flow rates exceed 100 scfm. Judging from the compounds listed in Table 1, this corresponds to compounds with boiling points (T_b)>150 C, or pure component vapor pressures <0.0001 atm evaluated at the subsurface temperature.

What Range of Vapor Flow Rates Can Realistically Be Achieved?

Question 3 requires that realistic vapor flow rates for the site-specific conditions be estimated. Equation 5, which predicts the flow rate per unit thickness of well screen Q/H [cm^3/s], can be used for this purpose:

$$\frac{Q}{H} = \pi \frac{k}{\mu} P_w \frac{[1 - (P_{Atm}/P_w)^2]}{\ln(R_w/R_I)} \tag{5}$$

where:

- k = soil permeability to air flow [cm^2] or [darcy]
- μ = viscosity of air = 1.8 x 10^{-4} g/cm-s or 0.018 cp
- P_w = absolute pressure at extraction well [g/cm-s^2] or [atm]
- P_{Atm} = absolute ambient pressure ≈ 1.01 x 10^6 g/cm-s^2 or 1 atm
- R_w = radius of vapor extraction well [cm]
- R_I = radius of influence of vapor extraction well [cm].

This equation is derived from the simplistic steady-state radial flow solution for compressible flow (Johnson et al. 1988), but should provide reasonable estimates for vapor flow rates. If k can be measured or estimated, then the only unknown parameter is the empirical "radius of influence" R_I. Values ranging from 9m (30 ft) to 30m (100 ft) are reported in the literature (Hutzler et al. 1988) for a variety of soil conditions, but fortunately Equation 5 is not sensitive to large changes in R_I. For estimation purposes, therefore, a value of R_I=12m (40 ft) can be used without a significant loss of accuracy. Typical vacuum well pressures range from 0.95 – 0.90 atm (20 – 40 in H_2O vacuum). Figure 5 presents predicted flow rates per unit well screen thickness Q/H, expressed in "standard" volumetric units Q*/H (= Q/ $H(P_w/P_{Atm})$ for a 5.1cm radius (4-in diameter) extraction well, and a wide range of soil permeabilities and applied vacuums. Here H denotes the thickness of the screened interval, which is often chosen to be equal to the thickness of the zone of soil contamination (this minimizes removing and treating any excess "clean" air). For other conditions the Q*/H values in Figure 5 can be multiplied by the following factors:

R_w = 5.1cm (2 in) R_I = 7.6m (25 ft) - multiply Q*/H by 1.09
R_w = 5.1cm (2 in) R_I = 23m (75 ft) - multiply Q*/H by 0.90
R_w = 7.6cm (3 in) R_I = 12m (40 ft) - multiply Q*/H by 1.08
R_w = 10cm (4 in) R_I = 12m (40 ft) - multiply Q*/H by 1.15
R_w = 10cm (4 in) R_I = 7.6m (25 ft) - multiply Q*/H by 1.27

As indicated by the preceding multipliers given, changing the radius of influence from 12m (40 ft) to 23 m (75 ft) only decreases the predicted flow rate by 10 percent. The largest uncertainty in flow rate calculations will be due to the air permeability value k, which can vary by one to three orders of magnitude across a site and can realistically only be estimated from boring log data within an order of magnitude. It is prudent, therefore, to choose a range of k values during this phase of the decision process. For example, if boring logs indicate fine sandy soils are present, then flow rates should be calculated for k values in the range of 0.1<k<1.0 darcy.

Will the Contaminant Concentrations and Realistic Vapor Flow Rates Produce Acceptable Removal Rates?

Again, estimated removal rates R_{est}, must be compared with an acceptable rate $R_{acceptable}$, as determined from Equation 4. Maximum removal rates are achieved when the induced vapor flow travels only through the zone of soil contamination and no mass-transfer limitations are encountered. In other words, all vapor flows through contaminated soils and becomes saturated with contaminant vapors. For this "best" case the estimated removal rate is given by Equation 2:

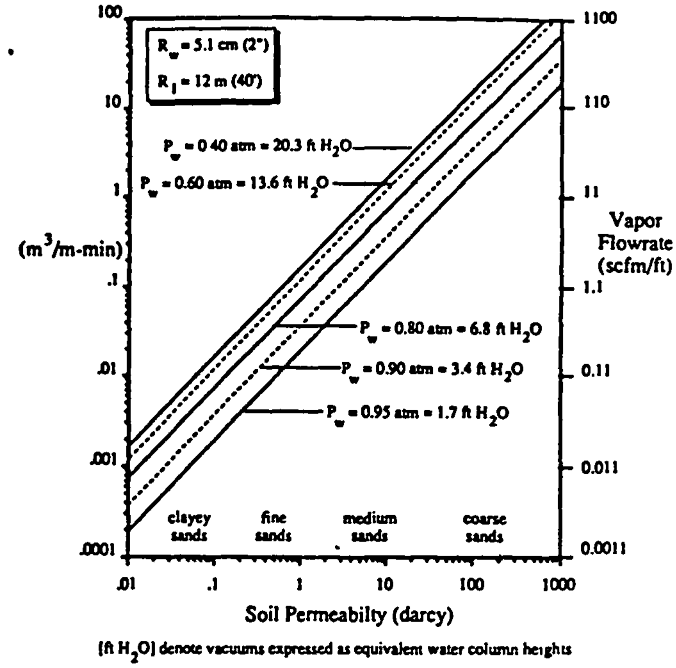


Figure 5. Predicted steady-state flow rates (per unit well screen thickness) for a range of soil permeabilities and applied vacuums (P_w).

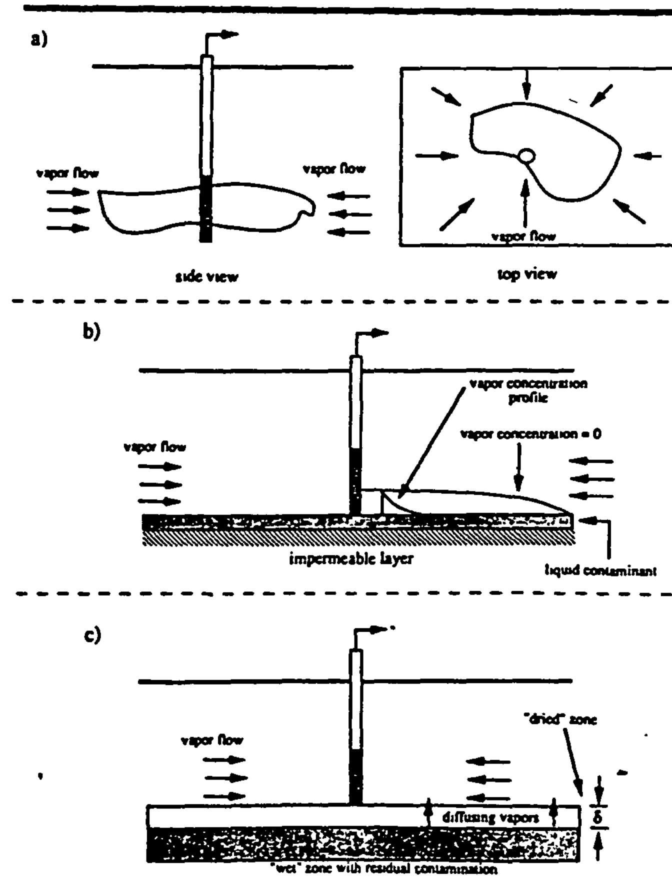


Figure 6. Scenarios for removal rate estimates.

$$R_{est} = C_{est}\, Q \qquad (2)$$

Changes in C_{est} are still being neglected with time due to composition changes. Other less optimal conditions are often encountered in practice and it is useful to be able to quantify how much lower the removal rate will be from the value predicted by Equation 2. We will consider the three cases illustrated in Figures 6a, b, and c.

In Figure 6a a fraction ϕ of the vapor flows through uncontaminated soil. The fraction can be roughly estimated by assessing the location of the well relative to the contaminant distribution. In Figure 6a for example, it appears that roughly 25 percent of the vapor flows through uncontaminated soil. The maximum removal rate for this case is then:

$$R_{est} = (1-\phi)\, Q\, C_{est} \tag{6}$$

In Figure 6b, vapor flows parallel to, but not through, the zone of contamination, and the significant mass transfer resistance is vapor phase diffusion. This would be the case for a layer of liquid hydrocarbon resting on top of an impermeable strata or the water table. This problem was studied by Johnson et al (1988) for the case of a single component. The solution is:

$$R_{est} = \eta Q\, C_{est}$$

$$\eta = \frac{1}{3H}(6D\mu/k)^{1/2}\,[\ln(R_I/R_w)/(P_{Atm} - P_w)]^{1/2}\sqrt{R_2^2 - R_1^2} \tag{7}$$

where:

η	= efficiency relative to maximum removal rate
D	= effective soil-vapor diffusion coefficient [cm²/s]
μ	= viscosity of air = 1.8×10^{-4} g/cm-s
k	= soil permeability to vapor flow [cm²]
H	= thickness of screened interval [cm]
R_I	= radius of influence of venting well [cm]
R_w	= venting well radius [cm]
P_{Atm}	= absolute ambient pressure = 1.016×10^6 g/cm-s²
P_w	= absolute pressure at the venting well [g/cm-s²]
$R_1 < r < R_2$	= defines region in which contamination is present.

Note that the efficiency η is inversely proportional to the screened interval thickness H because a larger interval will, in this geometry, pull in unsaturated air that has passed above the liquid-phase contamination. D is calculated by the Millington-Quirk (Millington and Quirk 1961) expression, which utilizes the molecular diffusion coefficient in air D°, the vapor-filled soil porosity ϵ_A, and the total soil porosity ϵ_T:

$$D = D^\circ \frac{\varepsilon_A^{3.33}}{\varepsilon_T^{2}} \tag{8}$$

where ϵ_A and ϵ_A are related by:

$$\varepsilon_A = \varepsilon_T - \rho_b\,\theta_M \tag{9}$$

Here ρ_b and Θ_M are the soil bulk density [g/cm³] and soil moisture content [g-H_2O/g-soil].

As an example, consider removing a layer of contamination bounded by sandy soil (k=1 darcy). A 5.1cm (4 in) radius vapor extraction well is being operated at P_w=0.90 atm (0.91×10^6 g/cm-s²), and the contamination extends from the region $R_1 = R_w$ = 5.1cm to R_2 = 9m (30 ft). The well is screened over a 3m (10 ft) interval. Assuming that:

ρ_b = 1.6 g/cm³
Θ_M = 0.10
D° = 0.087 cm²/s
ϵ_T = 0.30
R_I = 12 m

then the venting efficiency relative to the maximum removal rate (Equation 2), calculated from Equations 7 through 9 is:

η = 0.09 = 9%.

Figure 6c depicts the situation in which vapor flows primarily past, rather than through the contaminated soil zone, such as might be the case for a contaminated clay lens surrounded by sandy soils. In this case vapor-phase diffusion through the clay to the flowing vapor limits the removal rate. The maximum removal rate in this case occurs when the vapor flow is fast enough to maintain a low vapor concentration at the permeable/impermeable soil interface. At any time t a contaminant-free or "dried out" zone of low permeability will exist with a thickness δ. An estimate of the removal rate R_{est} from a contaminated zone extending from R_1 to R_2 is:

$$R_{est} = \pi\,(R_2^2 - R_1^2)\, C_{est}\, D/\delta(t) \tag{10}$$

where D is the effective porous media vapor diffusion coefficient (as calculated previously from Equations 8 and 9) and C_{est} is the estimated equilibrium vapor concentration (Equation 1). With time $\delta(t)$ will grow larger. In the case of a single component system the dry zone thickness can be calculated from the mass balance:

$$\rho_b\, C_s \frac{d\delta}{dt} = C_{est}\, D/\delta(\tau) \tag{11}$$

$$R_{est} = \pi(R_2^2 - R_1^2)\sqrt{\frac{C_{est}\, D\, C_s\, \rho_b}{2t}}$$

where C_s is the residual level of contamination in the low permeability zone [g-contamination/g-soil], and all other variables have been defined. The solution to Equations 10 and 11 yields the following equation that predicts the change in removal rate with time:

$$\delta(t) = \sqrt{\frac{2\, C_{est}\, D\, t}{\rho_b\, C_s}} \tag{12}$$

As an example, consider the case where benzene ($C_v = 3.19 \times 10^{-4}$ g/cm³ @20 C) is being removed from a zone extending from R_1 = 5.1cm to R_2 = 9m. The initial residual level is 10,000 ppm (0.01 g-benzene/g-soil), ρ_b = 1.6 g/cm³, D° = 0.087 cm²/s, and $\epsilon_T = \epsilon A$ = 0.30. Figure 7 presents the predicted removal rates and "dry" zone thickness $\delta(t)$ as a function of time. Note that it would take approximately one year to clean a layer 1.5m (5 ft) thick, for a compound as volatile as benzene. Equation 12 predicts high initial removal rates; in practice, however, the removal rate will be limited initially by the vapor-phase diffusion behavior described previously for Figure 6b.

Mixture removal rates for the situations depicted in Figures 6b and 6c are difficult to estimate because changes in composition and liquid-phase diffusion affect the behavior. Currently there are no simple analytical solutions for these situations, but it can be postulated that they should be less than the rates predicted previously for pure components.

The use of equilibrium-based models to predict required removal rates will be discussed under the next question.

What Residual, If Any, Will Be Left in the Soil? What Vapor Composition and Concentration Changes Will Occur With Time? How Do These Values Relate to the Regulatory Requirements?

As contaminants are removed during venting, the residual soil contamination level decreases and mixture compositions become richer in the less volatile compounds. Both of these processes result in decreased vapor concentrations, and hence, decreased removal rates with time. At low residual soil contamination levels (<500 ppm) Equation 1 becomes less valid as sorption and dissolution phenomena begin to affect the soil residual – vapor equilibrium. In the limit of low residual contamination levels, contaminant equilibrium vapor concentrations are expected to become proportional to the residual soil contaminant concentrations. As venting continues and residual soil levels decrease, therefore, it becomes more difficult to remove the residual contamination. It is important to realize that, even with soil venting, there are practical limitations on the final soil contamination levels that can be achieved. Knowledge of these limits is necessary to realistically set cleanup criteria and design effective venting systems.

The maximum efficiency of a venting operation is limited by the equilibrium partitioning of contaminants between the soil matrix and vapor phases. The maximum removal rate is achieved when the vapor being removed from an extraction well is in equilibrium with the contaminated soil. Models for predicting this maximum removal rate have been presented by Marley and Hoag (1984) and Johnson et al. (1988). The former considered only compositions in a residual free-phase, while the latter also considered the effects of sorption and dissolution processes. A complete discussion of the development of these models is not appropriate here, but we will discuss the use of the predictions.

The change in composition, vapor concentration, removal rate, and residual soil contamination level with time are functions of the initial residual composition, vapor extraction well flow rate, and initial soil contamination level. It is not necessary to generate predictions for every combination of variables, however, because with appropriate scaling all results will form a single curve for a given initial mixture composition. Figure 8a presents the results computed with the model presented by Johnson et al. (1988) for the "weathered" gasoline mixture whose composition is given by Table 2. The important variable that determines residual soil levels, vapor concentrations, and removal rates is the ratio Qt/M(t=0), which represents the volume of air drawn through the contaminated zone per unit mass of contaminant. In Figure 8, the scaled removal rate (or equivalently the vapor concentration) decreases with time as the mixture becomes richer in the less volatile compounds.

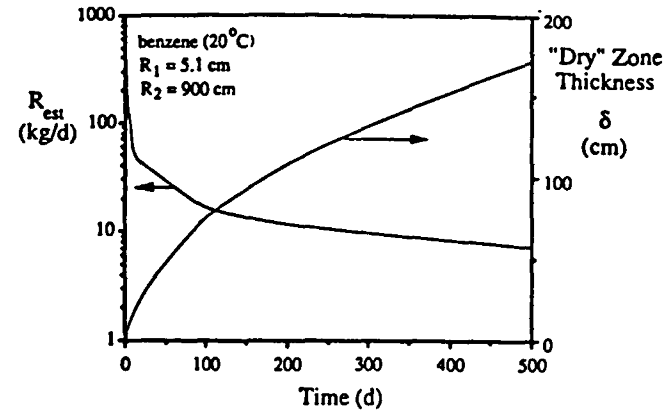


Figure 7. Estimated maximum removal rates for a venting operation limited by diffusion.

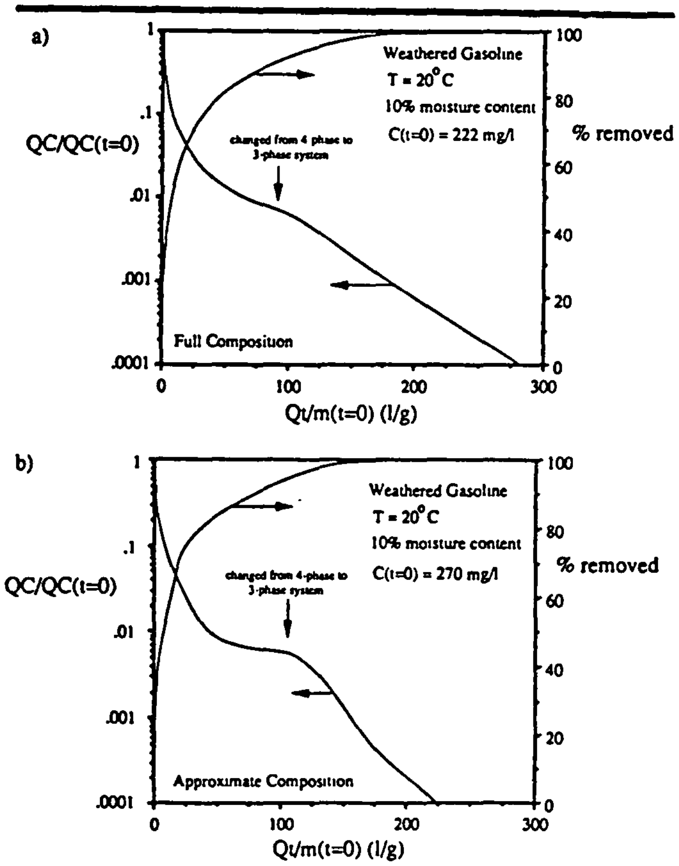


Figure 8. Maximum predicted removal rates for a weathered gasoline: (a) full composition (b) approximate composition.

While a detailed compositional analysis was available for this gasoline sample, an approximate composition based on a boiling point distribution curve predicts similar results. Figure 8b presents the results for the approximate mixture composition also given in Table 2.

Model predictions, such as those shown in Figure 8 for the gasoline sample defined by Table 2, can be used to estimate removal rates (if the vapor flow rate is specified), or alternatively the predictions can be used to estimate vapor flow rate requirements (if the desired removal rate is specified). For example, if we wanted to reduce the initial contamination level by 90 percent.

TABLE 2
Composition (Mass Fractions) of Fresh and Weathered Gasolines

Compound Name	M_w (g)	Fresh Gasoline	Weathered Gasoline	Approximate Composition
propane	44.1	0.0001	0.0000	0
isobutane	58.1	0.0122	0.0000	0
n-butane	58.1	0.0629	0.0000	0
trans-2-butene	56.1	0.0007	0.0000	0
cis-2-butene	56.1	0.0000	0.0000	0
3-methyl-l-butene	70.1	0.0006	0.0000	0
isopentane	72.2	0.1049	0.0069	0.0177
1-pentene	70.1	0.0000	0.0005	0
2-methyl-l-butene	70.1	0.0000	0.0008	0
2-methyl-1,3-butadiene	68.1	0.0000	0.0000	0
n-pentane	72.2	0.0586	0.0095	0
trans-2-pentene	70.1	0.0000	0.0017	0
2-methyl-2-butene	70.1	0.0044	0.0021	0
2-methyl-1,2-butadiene	68.1	0.0000	0.0010	0
3,3-dimethyl-1-butene	84.2	0.0049	0.0000	0
cyclopentane	70.1	0.0000	0.0046	0.0738
3-methyl-1-pentene	84.2	0.0000	0.0000	0
2,3-dimethylbutane	86.2	0.0730	0.0044	0
2-methylpentane	86.2	0.0273	0.0207	0
3-methylpentane	86.2	0.0000	0.0186	0
n-hexane	86.2	0.0283	0.0207	0
methylcyclopentane	84.2	0.0083	0.0234	0
2,2-dimethylpentane	100.2	0.0076	0.0064	0
benzene	78.1	0.0076	0.0021	0
cyclohexane	84.2	0.0000	0.0137	0.1761
2,3-dimethylpentane	100.2	0.0390	0.0000	0
3-methylhexane	100.2	0.0000	0.0355	0
3-ethylpentane	100.2	0.0000	0.0000	0
n-heptane	100.2	0.0063	0.0447	0
2,2,4-trimethylpentane	114.2	0.0121	0.0503	0
methylcyclohexane	98.2	0.0000	0.0393	0
2,2-dimethylhexane	114.2	0.0055	0.0207	0
toluene	92.1	0.0550	0.0359	0.1926
2,3,4-trimethylpentane	114.2	0.0121	0.0000	0
3-methylheptane	114.2	0.0000	0.0343	0
2-methylheptane	114.2	0.0155	0.0324	0
n-octane	114.2	0.0013	0.3000	0
2,4,4-trimethylhexane	128.3	0.0087	0.0034	0
2,2-dimethylheptane	128.3	0.0000	0.0226	0
ethylbenzene	106.2	0.0000	0.0130	0
p-xylene	106.2	0.0957	0.0151	0
m-xylene	106.2	0.0000	0.0376	0.1641
3,3,4-trimethylhexane	128.3	0.0281	0.0056	0
o-xylene	106.2	0.0000	0.0274	0
2,2,4-trimethylheptane	142.3	0.0105	0.0012	0
n-noname	128.3	0.0000	0.0382	0
3,3,5-trimethylheptane	142.3	0.0000	0.0000	0
n-propylbenzene	120.2	0.0841	0.0117	0.1455
2,3,4-trimethylheptane	142.3	0.0000	0.0000	0
1,3,5-trimethylbenzene	120.2	0.0411	0.0493	0
1,2-4-trimethylbenzene	120.2	0.0213	0.0707	0
n-decane	142.3	0.0000	0.0140	0
methylpropylbenzene	134.2	0.0351	0.0170	0
dimethylethylbenzene	134.2	0.0307	0.0289	0.0534
n-undecane	156.3	0.0000	0.0075	0
1,2,4,5-tetramethylbenzene	134.2	0.0133	0.0056	0
1,2,3,4-tetramethylbenzene	134.2	0.0129	0.0704	0.1411
1,2,4-trimethyl-5-ethylbenzene	148.2	0.0405	0.0651	0
n-dodecane	170.3	0.0230	0.0000	0
napthalene	128.2	0.0045	0.0076	0
n-hexylbenzene	162.3	0.0000	0.0147	0.0357
methylnapthalene	142.2	0.0023	0.0134	0
Total		1.0000	1.0000	1.00000

then Figure 8 predicts that ≈ 100 l-air/g-gasoline will be required. This is the minimum amount of vapor required, because it is based on an equilibrium-based model. The necessary minimum average vapor flow rate is then equal to the spill mass times the minimum required vapor flow/mass gasoline divided by the desired duration of venting. Use of this approach is illustrated in the service station site example provided at the end of this paper.

Figure 8 also illustrates that there is a practical limit to the amount of residual contaminant that can be removed by venting alone. For example, it will take a minimum of 100 l-vapor/g-gasoline to remove 90 percent of the weathered gasoline defined in Table 2, while it will take about 200 l-air/g-gasoline to remove the remaining 10 percent. In the case of gasoline, by the time 90 percent of the initial residual has been removed, the residual consists of relatively insoluble and nonvolatile compounds. It is important to recognize this limitation of venting, and when setting realistic cleanup target levels, they should be based on the potential environmental impact of the residual rather than any specific total residual hydrocarbon levels. Because mandated cleanup levels are generally independent of the remediation method, this also indicates that soil venting will often be one of many processes used during a given site remediation. It is not difficult to envision that in the future soil venting may be followed or coupled with enhanced biodegradation to achieve lower cleanup levels.

It is appropriate to mention at this point that the mathematical models presented in this paper are being used as "tools" to help plan and design venting system. As with any models, they are mathematical descriptions of processes that at best approximate real phenomena, and care should be taken not to misapply or misinterpret the results.

Are There Likely to Be Any Negative Effects of Soil Venting?

It is possible that venting will induce the migration of off-site contaminant vapors toward the extraction wells. This may occur at a service station, which is often in close proximity to other service stations. If this occurs, one could spend a lot of time and money to unknowingly clean up someone else's problem. The solution is to establish a "vapor barrier" at the perimeter of the contaminated zone. This can be accomplished by allowing vapor flow into any perimeter ground water monitoring wells (which often have screened intervals extending above the saturated zone), which then act as passive air supply wells. In other cases it may be necessary to install passive air injection wells, or trenches, as illustrated in Figure 9a.

As pointed out by Johnson et al. (1988), the application of a vacuum to extraction wells can also cause a water table rise. In many cases contaminated soils lie just above the water table and they become water saturated, as illustrated in Figure 9b. The maximum rise occurs at, or below the vapor extraction well, where the water table rise will be equal to the vacuum at that point

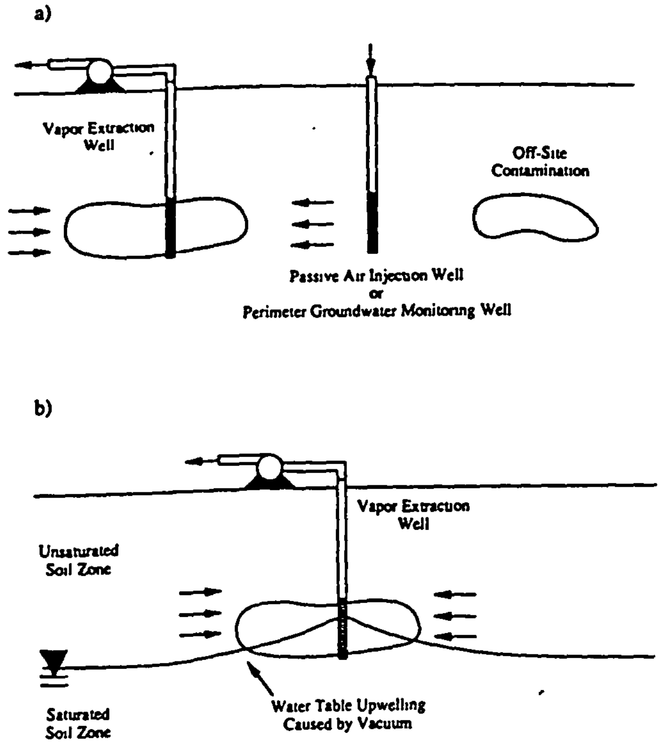


Figure 9. (a) Use of passive vapor wells to prevent migration of off-site contaminant vapors. (b) Water table rise caused by the applied vacuum.

expressed as an equivalent water column height (i.e., in ft H_2O). The recommended solution to this problem is to install a dewatering system, with ground water pumping wells located as close to vapor extraction wells as possible. The dewatering system must be designed to ensure that contaminated soils remain exposed to vapor flow. Other considerations not directly related to venting system design, such as soluble plume migration control and free-liquid product yield, will also be factors in the design of the ground water pumping system.

Design Information

If venting is still a remediation option after answering the questions above, then more accurate information must be collected. Specifically, the soil permeability to vapor flow, vapor concentrations, and aquifer characteristics need to be determined. These are obtained by two field experiments: air permeability and ground water pumping tests, described briefly next.

Air Permeability Tests

Figure 10 depicts the setup of an air permeability test. The object of this experiment is to remove vapors at a constant rate from an extraction well, while monitoring with time the transient subsurface pressure distribution at fixed points. Effluent vapor concentrations are also monitored. It is important that the test be conducted properly to obtain accurate design information. The extraction well should be screened through the soil zone that will be vented during the actual operation. In many cases existing ground water monitoring wells are sufficient, if their screened sections extend above the water table. Subsurface pressure monitoring probes can be

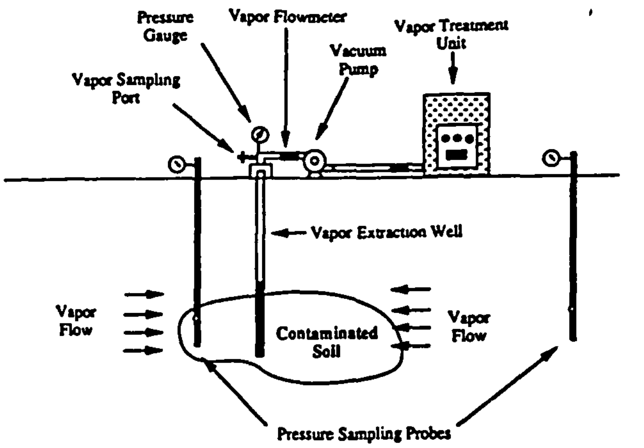


Figure 10. Air-permeability test system.

driven soil-vapor sampling probes (for <20 ft deep contamination problems) or more permanent installations.

Flow rate and transient pressure distribution data are used to estimate the soil permeability to vapor flow. The expected change in the subsurface pressure distribution with time P′(r,t) is predicted (Johnson et al.) by:

$$P' = \frac{Q}{4\pi m(k/\mu)} \int_{\frac{r^2 \varepsilon \mu}{4kP_{Atm}\, t}}^{\infty} \frac{e^{-x}}{x}\, dx \qquad (13)$$

For $(r^2\, \epsilon\mu/4kP_{Atm}t)<0.1$ Equation 13 can be approximated by:

$$P' = \frac{Q}{4\pi m(k/\mu)} \left[-0.5772 - \ln\left(\frac{r^2\, \varepsilon\mu}{4kP_{Atm}}\right) + \ln(t)\right] \qquad (14)$$

Here:

- P' = "gauge" pressure measured at distance r and time t
- m = stratum thickness
- r = radial distance from vapor extraction well
- k = soil permeability to air flow
- μ = viscosity of air = 1.8×10^{-4} g/cm-s
- ϵ = air-filled soil void fraction
- t = time
- Q = volumetric vapor flow rate from extraction well
- P_{Atm} = ambient atmospheric pressure = 1.0 atm = 1.013×10^6 g/cm-s².

Equation 14 predicts a plot of ρ′-vs- In(t) should be a straight line with slope A and y-intercept B equal to:

$$A = \frac{Q}{4\pi m(k/\mu)}$$

$$B = \frac{Q}{4\pi m(k/\mu)} \left[-0.5772 - \ln\left(\frac{r^2\, \varepsilon\mu}{4kP_{Atm}}\right)\right] \qquad (15)$$

The permeability to vapor flow can then be calculated from the data by one of two methods. The first is applicable when Q and m are known. The calculated slope A is used:

$$k = \frac{Q\mu}{4A\pi m} \qquad (16)$$

The second approach must be used whenever Q or m is not known. In this case the values A and B are both used:

$$k = \frac{r^2\, \varepsilon\mu}{4P_{Atm}} \exp\left(\frac{B}{A} + 0.5772\right) \qquad (17)$$

Equation 13 can also be used to choose the locations of subsurface pressure monitoring points before conducting the air permeability test, given an estimation of k and the flow rate to be used.

Vapor samples should be taken at the beginning and end of the air permeability test, which should be conducted for a long enough time to extract at least one "pore volume" V_P of vapor from the contaminated soil zone. This ensures that all vapors existing in the formation prior to venting are removed. The vapor concentration at the start of the test is representative of the equilibrium vapor concentration, while the concentration measured after one pore volume has been extracted gives an indication of realistic removal rates and the mixing or diffusional limitations discussed in association with Figure 6. The time τ_P for one pore volume to be removed is:

$$\tau_p = V_P/Q = \epsilon_A\, \pi R^2\, H/Q \qquad (18)$$

where R, H, ϵ_A, and Q are the radius of the zone of contamination, vertical thickness of the zone of contamination, air-filled void fraction, and volumetric vapor flow rate from the extraction well. For example, consider the case where R=12 m, H=3 m, ϵ_A=0.35, and Q=0.57 m³/min (20 ft³/min). Then τ_P=475 m³/0.57 m³/min=833 min=14 h.

Ground Water Pumping Tests

To achieve efficient venting, the hydrocarbon-contaminated soil has to be exposed to air flow, which in turn requires that the water table be lowered to counteract the water upwelling effect caused by the decreased vapor pressure in the vicinity of a venting well (Johnson et al. 1988) and to possibly expose contaminated soil below the water table. Thus the ground water pumping system has to have a sufficient pumping rate and be operated for a long enough time period to obtain the required drawdowns. Because most venting systems are installed above phreatic aquifers, two aquifer parameters are needed for the design: average transmissivity T and storage coefficient S. These parameters can be estimated using the results of the standard transient ground water pumping test with a constant pumping rate (Bear 1979). Using the estimated values, the required pumping rate may be calculated as follows:

$$Q = 4\pi T\, S(r,t)/W(u) \qquad (19)$$

where: W(u) is the well function (Bear 1979) of u = Sr²/

4Tt, and $s(r,t)$ is the required drawdown at distance r and pumping time equal to t.

System Design

In this section the questions that must be answered in order to design an in situ soil-venting system will be discussed. It is not the authors' intention to provide a generic "recipe" for soil-venting system design; instead, a structured thought process to guide in choosing the number of extraction wells, well spacing, well construction, etc. is suggested. Even in a structured thought process, intuition, and experience play important roles. There is no substitute for a good fundamental understanding of vapor flow processes, transport phenomena, and ground water flow.

Choosing the Number of Vapor Extraction Wells

Three methods for choosing the number of vapor extraction wells are outlined in the following text. The greatest number of wells from these three methods is then the value that should be used. The objective is to satisfy removal rate requirements and achieve vapor removal from the entire zone of contamination.

For the first estimate residual contaminant composition and vapor concentration changes with time are neglected. The acceptable removal rate $R_{acceptable}$ is calculated from Equation 4, while the estimated removal rate from a single well R_{est} is estimated from a choice of Equations 2, 6, 7, or 12 depending on whether the specific site conditions are most like Figure 6a, 6b, or 6c. The number of wells N_{wells} required to achieve the acceptable removal rate is:

$$N_{wells} = R_{acceptable}/R_{est} \tag{20}$$

Equations 2, 6, and 7 require vapor flow estimates, which can be calculated from Equation 5 using the measured soil permeability and chosen extraction well vacuum P_w. At this point one must determine what blowers and vacuum pumps are available because the characteristics of these units will limit the range of feasible (P_w, Q) values. For example, a blower that can pump 100 scfm at 2 in. H_2O vacuum may only be able to pump 10 scfm at 100 in. H_2O vacuum.

The second method, which accounts for composition changes with time, utilizes model predictions, such as those illustrated in Figure 8. Recall that equilibrium-based models are used to calculate the minimum vapor flow to achieve a given degree of remediation. For example, if we wish to obtain a 90 percent reduction in residual gasoline levels, Figure 8 indicates that ≈ 100 l-vapor/g-gasoline must pass through the contaminated soil zone. If our spill mass is 1500kg (=500 gal), then a minimum of 1.5×10^8 l-vapor must pass through the contaminated soil zone. If the target cleanup period is six months, this corresponds to a minimum average vapor flow rate of 0.57 m^3/min (=20 cfm). The minimum number of extraction wells is then equal to the required minimum average flow rate/flow rate-per-well.

The third method for determining the number of wells ensures that vapors and residual soil contamination are removed from the entire zone of contamination N_{min}. This is simply equal to the ratio of the area of contamination $A_{contamination}$, to the area of influence of a single venting well πR_I^2:

$$N_{min} = \frac{A_{contamination}}{\pi R_I^2} \tag{21}$$

This requires an estimate of R_I, which defines the zone in which vapor flow is induced. In general, R_I depends on soil properties of the vented zone, properties of surrounding soil layers, the depth at which the well is screened, and the presence of any impermeable boundaries (water table, clay layers, surface seal, building basement, etc.). At this point it is useful to have some understanding of vapor flow patterns because, except for certain ideal cases (Wilson et al. 1988), one cannot accurately predict vapor flow paths without numerically solving vapor-flow equations. An estimate for R_I can be obtained by fitting radial pressure distribution data from the air permeability test to the steady-state radial pressure distribution equation (Johnson et al. 1988):

$$P(r) = P_w \left[1 + \left(1 - \left(\frac{P_{Atm}}{P_w}\right)^2\right) \frac{\ln(r/R_w)}{\ln(R_w/R_I)}\right]^{1/2} \tag{22}$$

where $P(r)$, P_{Atm}, P_w, and R_w are the absolute pressure measured at a distance r from the venting well, absolute ambient pressure, absolute pressure applied at the vapor extraction well, and extraction well radius, respectively. Given that these tests are usually conducted for less than a day, the results will generally underestimate R_I. If no site-specific data are available, one can conservatively estimate R_I based on the published reports from in situ soil-venting operations. Reported R_I values for permeable soils (sandy soils) at depths greater than 20 feet below ground surface, or shallower soils beneath good surface seals, are usually 10m – 40m (Hutzler et al. 1988). For less permeable soils (silts, clays), or more shallow zones R_I is usually less.

Choosing Well Location, Spacing, Passive Wells, and Surface Seals

To be able to successfully locate extraction wells, passive wells, and surface seals one must have a good understanding of vapor flow behavior. Well locations should be chosen to ensure adequate vapor flow through the contaminated zone, while minimizing vapor flow through other zones.

If one well is sufficient, it should almost always be placed in the geometric center of the contaminated soil zone, unless it is expected that vapor flow channeling along a preferred direction will occur. In that case the well should be placed so as to maximize air flow through the contaminated zone.

When multiple wells are used it is important to consider the effect that each well has on the vapor flow to all other wells. For example, if three extraction wells are required at a given site, and they are installed in the triplate design shown in Figure 11a, this would result

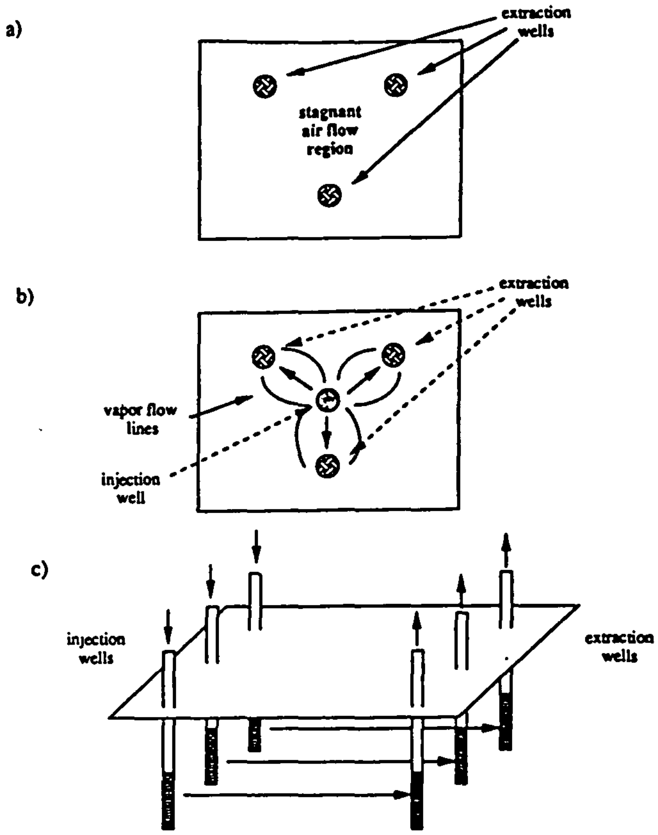


Figure 11. Venting well configurations.

in a "stagnant" region in the middle of the wells where air flow would be small in comparison to the flow induced outside the triplate pattern boundaries. This problem can be alleviated by the use of "passive wells" or "forced injection" wells as illustrated in Figure 11b (it can also be minimized by changing the vapor flow rates from each well with time). A passive well is simply a well that is open to the atmosphere; in many cases ground water monitoring wells are suitable. If a passive or forced injection well is to have any positive effect, it must be located within the extraction well's zone of influence. Forced injection wells are simply vapor wells into which air is pumped rather than removed. One must be careful in choosing the locations of forced injection wells so that contaminant vapors are captured by the extraction wells, rather than forced off-site. To date there have not been any detailed reports of venting operations designed to study the advantages/disadvantages of using forced injection wells. Figure 11c presents another possible extraction/injection well combination. As illustrated in Figure 9, passive wells can also be used as vapor barriers to prevent on-site migration of off-site contamination problems.

For shallow contamination problems (<4m below ground surface) vapor extraction trenches combined with surface seals may be more effective than vertical wells. Trenches are usually limited to shallow soil zones because the difficulty of installation increases with depth.

Surface seals, such as polymer-based liners and asphalt, concrete, or clay caps, are sometimes used to control the vapor-flow paths. Figure 12 illustrates the effect that a surface seal will have on vapor-flow pat-

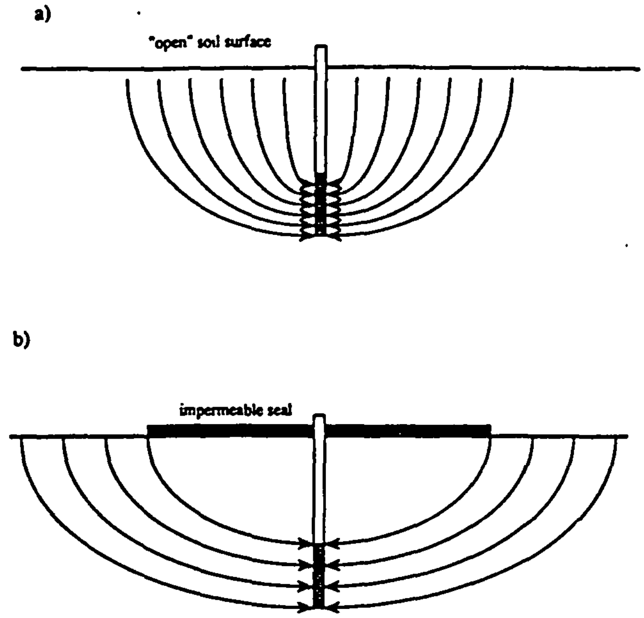


Figure 12. Effect of surface seal on vapor flow path.

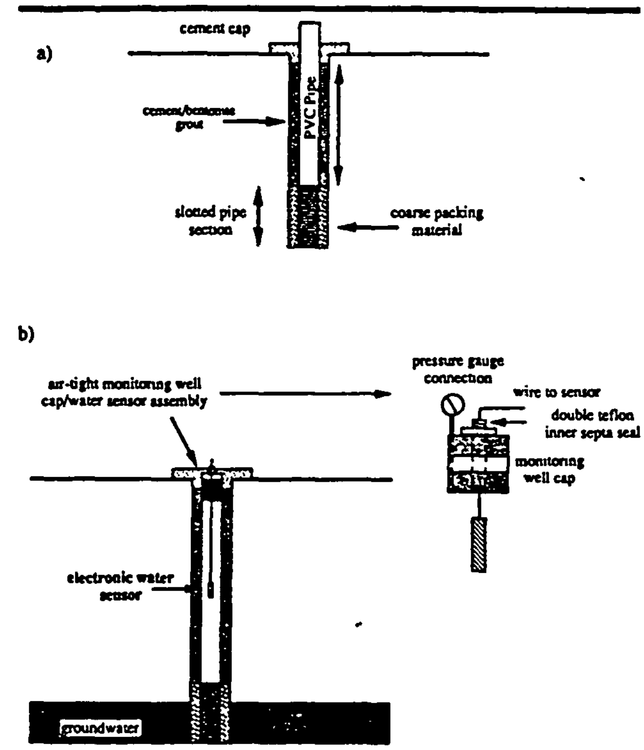


Figure 13. (a) Extraction well construction, and (b) air-tight ground water level measuring system.

terns. For shallow treatment zones (<5m) the surface seal will have a significant effect on the vapor flow paths, and seals can be added or removed to achieve the desired vapor flow path. For wells screened below 8m the influence of surface seals becomes less significant.

Well Screening and Construction

Wells should be screened only through the zone of contamination, unless the permeability to vapor flow is so low that removal rates would be greater if flow were induced in an adjacent soil layer (see Figure 6). Removal rate estimates for various mass-transfer limited scenarios can be calculated from Equations 7 and 12.

Based on Equation 5, the flow rate is expected to increase by 15 percent when the extraction well diameter is increased from 10cm (4 in) to 20cm (8 in). This implies that well diameters should be as large as is practically possible.

A typical well as shown in Figure 13a is constructed from slotted pipe (usually PVC). The slot size and number of slots per inch should be chosen to maximize the open area of the pipe. A filter packing, such as sand or gravel, is placed in the annulus between the borehole and pipe. Vapor extraction wells are similar to ground water monitoring wells in construction but there is no need to filter vapors before they enter the well. The filter packing, therefore, should be as coarse as possible. Any dust carried by the vapor flow can be removed by an above-ground filter. Bentonite pellets and a cement grout are placed above the filter packing. It is important that these be properly installed to prevent a vapor flow "short-circuiting." Any ground water monitoring wells installed near the extraction wells must also be installed with good seals.

Vapor Treatment

Currently, there a-four main treatment processes available:

Vapor combustion units: Vapors are incinerated and destruction efficiencies are typically >95 percent. A supplemental fuel, such as propane, is added before combustion unless extraction well vapor concentrations are on the order of a few percent by volume. This process becomes less economical as vapor concentrations decrease below ~ 10,000 ppm_v.

Catalytic oxidation units: Vapor streams are heated and then passed over a catalyst bed. Destruction efficiencies are typically >95 percent. These units are used for vapor concentrations <8000 ppm_v. More concentrated vapors can cause catalyst bed temperature excursions and meltdown.

Carbon beds: Carbon can be used to treat almost any vapor streams, but is only economical for very low emission rates (<100 g/d)

Diffuser stacks: These do not treat vapors, but are the most economical solution for areas in which they are permitted. They must be carefully designed to minimize health risks and maximize safety.

Ground Water Pumping System

In cases where contaminated soils lie just above or below the water table, ground water pumping systems will be required to ensure that contaminated soils remain exposed. In designing a ground water pumping system it is important to be aware that upwelling (draw-up) of the ground water table will occur when a vacuum is applied at the extraction well (see Figure 9b). Because the upwelling will be greatest at the extraction wells, ground water pumping wells should be located within or as close to the extraction wells as possible. Their surface seals must be airtight to prevent unwanted short-circuiting of airflow down the ground water wells.

System Integration

System components (pumps, wells, vapor treating units, etc.) should be combined to allow maximum flexibility of operation. The review by Hutzler et al. (1988) provides descriptions of many reported systems. Specific requirements are:

Separate valves, flow meters, and pressure gauges for each extraction and injection well.

- Air filter to remove particulates from vapors upstream of the pump and flow meter.
- Knock-out pot to remove any liquid from vapor stream upstream of the pump and flow meter.

Monitoring

The performance of a soil-venting system must be monitored in order to ensure efficient operation, and to help determine when to shut off the system. At a minimum the following should be measured:

- **Date and time** of measurement.
- **Vapor flow rates** from extraction wells and into injection wells: These can be measured by a variety of flow meters including pitot tubes, orifice plates and rotameters. It is important to have calibrated these devices at the field operating pressures and temperatures.
- **Pressure readings** at each extraction and injection well can be measured with manometers or magnahelic gauges.
- **Vapor concentrations and compositions** from extraction wells: total hydrocarbon concentration can be measured by an on-line total hydrocarbon analyzer calibrated to a specific hydrocarbon. This information is combined with vapor flow rate data to calculate removal rates and the cumulative amount of contaminant removed. In addition, for mixtures the vapor composition should be periodically checked. It is impossible to assess if vapor concentration decreases with time are due to compositional changes or some other phenomena (mass transfer resistance, water table upwelling, pore blockage, etc.) without this information. Vapor samples can be collected in evacuated gas sampling cylinders, stored, and later analyzed.
- **Temperature:** ambient and soil.
- **Water table level** (for contaminated soils located near the water table): It is important to monitor the water table level to ensure that contaminated soils remain exposed to vapor flow. Measuring the water table level during venting is not a trivial task because the monitoring well must remain sealed. Uncapping the well releases the vacuum and any effect that it has on the water table level. Figure 13b illustrates a monitoring well cap (constructed by Applied Geosciences Inc., Tustin, California) that allows one to simultaneously measure the water table level and vacuum in a monitoring well. It is constructed from a commercially available monitoring well cap and utilizes an electronic water level sensor.

Other valuable, but optional measurements are:

Soil-gas vapor concentrations and compositions: These should be measured periodically at different radial distances from the extraction well. Figure 14

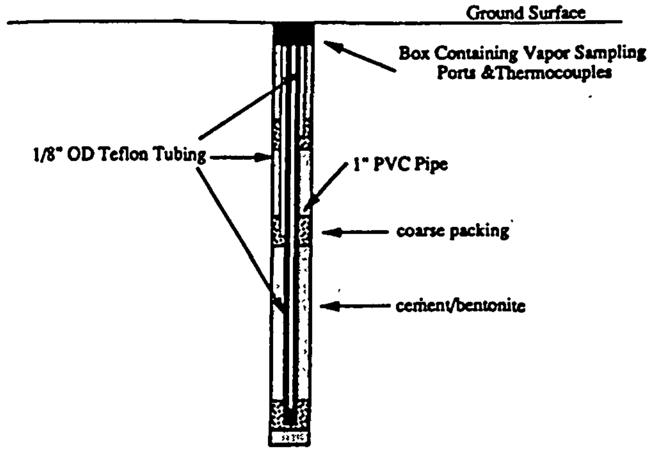


Figure 14. Vadose zone monitoring well installation.

shows the construction of a permanent monitoring installation that can be used for vapor sampling and subsurface temperature measurements. Another alternative for shallow contamination zones is the use of soil-gas survey probes. Data from soil-gas probes are valuable for two reasons: (1) by comparing extraction well concentrations with soil-gas concentrations it is possible to estimate the fraction of vapor that is flowing through the contaminated zone $\phi = C_{extraction\ well}/C_{soil\ gas}$, and (2) it is possible to determine if the zone of contamination is shrinking toward the extraction well, as it should with time. Three measuring points are probably sufficient if one is located near the extraction well, one is placed near the original edge of the zone of contamination, and the third is placed somewhere in between.

These monitoring installations can also be useful for monitoring subsurface vapors after venting has ceased.

Determining When to Turn Off the System

Target soil cleanup levels are often set on a site-by-site basis, and are based on the estimated potential impact that any residual may have on air quality, ground water quality, or other health standards. They may also be related to safety considerations (explosive limits). Generally, confirmation soil borings, and sometimes soil-vapor surveys are required before closure is granted. Because these analyses can be expensive and often disrupt the normal business of a site, it would be valuable to be able to determine when confirmation borings should be taken. If the monitoring is done as suggested previously, then the following criteria can be used:

Cumulative amount removed: Determined by integrating the measured removal rates (flow rate x concentration) with time. While this value indicates how much contaminant has been removed, it is usually not very useful for determining when to take confirmation borings unless the original spill mass is known accurately. In most cases that information is not available and cannot be calculated accurately from soil-boring data.

- **Extraction well vapor c ncentrations:** The vapor concentrations are good indications of how effectively the venting system is working, but decreases in vapor extraction well concentrations are not strong evidence that soil concentrations have decreased. Decreases may also be due to other phenomena such as water table level increases, increased mass transfer resistance due to drying, or leaks in the extraction system.
- **Extraction well vapor composition:** When combined with vapor concentrations these data offer more insight into the effectiveness of the system. If the total vapor concentration decreases without a change in composition, it is probably due to one of the phenomena mentioned previously, and is not an indication that the residual contamination has been significantly reduced. If a decrease in vapor concentration is accompanied by a shift in composition toward less volatile compounds, on the other hand, it is most likely due to a change in the residual contaminant concentration. For residual gasoline cleanup, for example, one might operate a venting system until benzene, toluene, and xylenes were not detected in the vapors. The remaining residual would then be composed of larger molecules, and it can be argued that these do not pose a health threat through volatilization or leaching pathways.
- **Soil-gas contaminant concentration and composition:** These data are the most useful because it yields information about the residual composition and extent of contamination. Vapor concentrations cannot, in general, be used to determine the residual level, except in the limit of low residual levels (note that Equation 1 is independent of residual concentration). It is important to consider the effect of continued soil-venting system operation on soil-gas sampling results. Results taken during operation, or immediately after shutdown, can be used to assess the spatial extent of contamination and composition of the vapors. After the system is shut down, vapors will begin to migrate away from the source and equilibrate on a larger scale. True soil-vapor concentrations can be measured once equilibrium concentrations are attained in the sampling zone; at least two sampling times will be required to determine that equilibration has occurred. Due to the diffusion of vapors, samples taken after shutdown are not good indicators of the spatial extent of the contaminated zone.

Other Factors

Increased Biodegradation

It is often postulated that because the air supply to the vadose zone is increased, the natural aerobic microbiological activity is increased during venting. While the argument is plausible and some laboratory data are available (Salanitro et al. 1989), conclusive evidence supporting this theory has yet to be presented. This is due in part to the difficulty in making such a measurement. A mass balance approach is not likely to be useful because the initial spill mass is generally not known with sufficient accuracy. An indirect method would be to measure CO_2 levels in the extraction well vapors, but this in itself does not rule out the possibility that O_2 is converted to CO_2 before the vapors pass through the contaminated soil zone. The best approach is to measure the O_2/CO_2 concentrations in the vapors at the edge of the contaminated zone, and in the vapor extraction wells. If the CO_2/O_2 concentration ratio increases as the vapors pass through the contaminated soil, one can surmise that a transformation is occurring, although other possible mechanisms (inorganic reactions) must be considered. An increase in aerobic microbial populations would be additional supporting evidence.

In Situ Heating/Venting

The main property of a compound that determines whether or not it can be removed by venting is its vapor pressure, which increases with increasing temperature. Compounds that are considered non-volatile, therefore, can be removed by venting if the contaminated soil is heated to the proper temperature. In situ heating/venting systems utilizing radio-frequency heating and conduction heating are currently under study (Dev et al. 1988). An alternative is to reinject heated vapors from catalytic oxidation or combustion units into the contaminated soil zone.

Air Sparging

Due to seasonal ground water level fluctuations, contaminants sometimes become trapped below the water table. In some cases ground water pumping can lower the water table enough to expose this zone, but in other cases this is not practical. One possible solution is to install air sparging wells and then inject air below the water table. Vapor extraction wells would then capture the vapors that bubbled up through the ground water. To date, success of this approach has yet to be demonstrated. This could have a negative effect if foaming, formation plugging, or downward migration of the residual occurred.

Application of the Design Approach to a Service Station Remediation

In the following, the use of the approach discussed previously and outlined in Figure 2, is demonstrated for a service station remediation.

Preliminary Site Investigation

Prior to sampling it was estimated that 2000 gallons of gasoline had leaked from a product line at this operating service station site. Several soil borings were drilled and the soil samples were analyzed for total petroleum hydrocarbons (TPH) and other specific compounds (benzene, toluene, xylenes) by a heated-headspace method utilizing a field GC-FID. Figure 15 summarizes some of the results for one transect at this site. The following relevant information was collected:

- Based on boring logs there are four distinct soil layers between 0 – 18m (0 – 60 ft) below ground surface (BGS). Figure 15 indicates the soil type and location of each of these layers.

  Depth to ground water was 15m, with fine to medium sand soils.

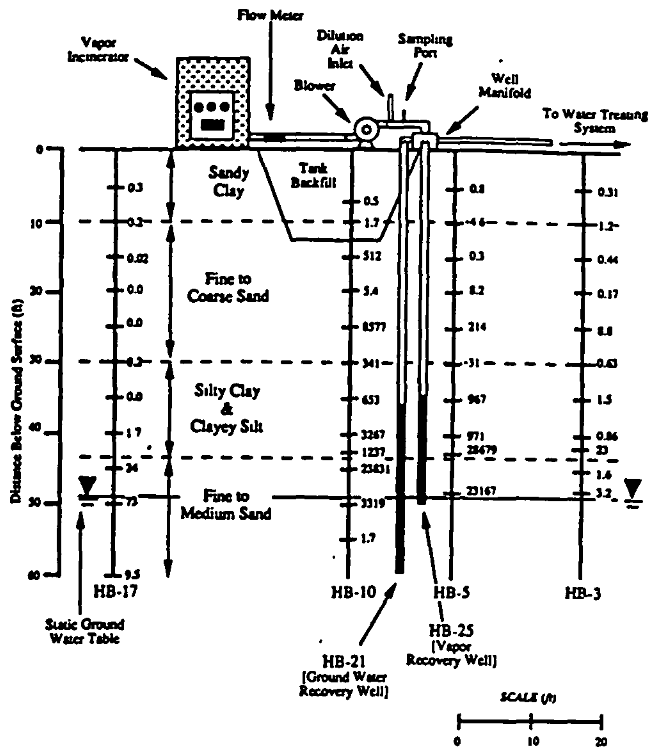


Figure 15. Initial total hydrocarbon distribution [mg/kg-soil] and location of lower zone vent well.

- The largest concentrations of hydrocarbons were detected in the sandy and silty clay layers adjacent to the water table. Some residual was detected below the water table. Based on the data presented in Figure 15 it is estimated that ≈ 4000kg of hydrocarbons are present in the lower two soil zones.
- Initially there was some free-liquid gasoline floating on the water table: this was subsequently removed by pumping. A sample of this product was analyzed and its approximate composition (≈20 percent of the compounds could not be identified) is listed in Table 2 as the "weathered gasoline." The corresponding boiling point distribution curve for this mixture has been presented in Figure 3.
- Vadose zone monitoring installations similar to the one pictured in Figure 14 were installed during the preliminary site investigation.

Deciding if Venting Is Appropriate

For the remainder of the analysis the contaminated soils located just above the water table will be the focus.

- What contaminant vapor concentrations are likely to be obtained?

Based on the composition given in Table 2, and using Equation 1, the predicted saturated TPH vapor concentration for this gasoline is:

C_{est} = 220 mg/L

Using the "approximate" composition listed in Table 2 yields a value of 270 mg/L. The measured soil-vapor concentration obtained from the vadose zone monitoring well was 240 mg/L. Due to composition changes with time, this will be the maximum concentration obtained during venting.

- Under ideal flow conditions is this concentration great enough to yield acceptable removal rates?

Equation 4 was used to calculate $R_{acceptable}$. Assuming M_{spill} = 4000kg and τ = 180 d, then:

$R_{acceptable}$ = 22 kg/d

Using Equation 2, C_{est} = 240 mg/L, and Q = 2800 l/min (100 cfm):

R_{est} = 970 kg/d

which is greater than $R_{acceptable}$.

What range of vapor flow rates can realistically be achieved?

Based on boring logs, the contaminated zone just above the water table is composed of fine to medium sands, which have an estimated permeability 1< k < 10 darcy. Using Figure 5, or Equation 5, the predicted flow rates for an extraction well vacuum P_w = 0.90 atm are:

$0.04 < Q < 0.4$ m^3/m-min R_w = 5.1cm, R_I = 12m

$0.43 < Q < 4.3$ ft^3/ft-min R_w = 2.0 in, R_I = 40 ft.

The thickness of this zone and probable screen thickness of an extraction well is about 2m (6.6 ft). The total flow rate per well through this zone is estimated to be 0.08<Q<0.8 m^3/min (2.8 cfm<Q<28 cfm).

Will the contaminant concentrations and estimated flow rates produce acceptable removal rates?

Using C_{est}=240 mg/L, the maximum removal rates likely to be obtained are calculated from Equation 2:

28 kg/d < $(R_{est})_{max}$ < 280 kg/d.

To be conservative, we will guess that only 50 percent of the vapor actually flows through contaminated soils, so our estimated removal rate per well will be half of these values. The estimated acceptable removal rate $R_{acceptable}$ = 22 kg/d falls within this range. Of course this calculation did not take into account the possibility of vapor concentration decreases during venting. This will be taken into account in the next subsection.

What residual, if any, will be left in the soil?

A target cleanup level for most gasoline spill sites is <1000 mg/kg TPH residual; in some states the target level is <100 mg/kg TPH. If the initial residual level is ≈10,000 ppm, then at least 90 percent of the initial residual needs to be removed. According to the curves in Figure 8, which represent the maximum removal rates for the gasoline analyzed at this site, approximately 100 l-vapor/g-residual will have to pass through the contaminated zone to achieve this target. Based on our estimated initial residual of 4000kg TPH, 4 x 10^8 l-vapor are required. Over a six-month period this corresponds to an average flow rate Q=1.5 m^3/min (54 cfm). Recall that since this corresponds to the maximum removal rate, it is the minimum required flow rate.

Are there likely to be any negative effects of soil venting?

Given that the contaminated soils are located just above and below the water table, water table upwelling during venting must be considered here.

Air Permeability Test

Figure 16 presents data obtained from the air permeability test of this soil zone. In addition to vapor extraction tests, air injection tests were conducted. The data are analyzed in the same manner as discussed for vapor extraction tests. Accurate flow rate (Q) values were not measured, therefore, Equation 17 was used to

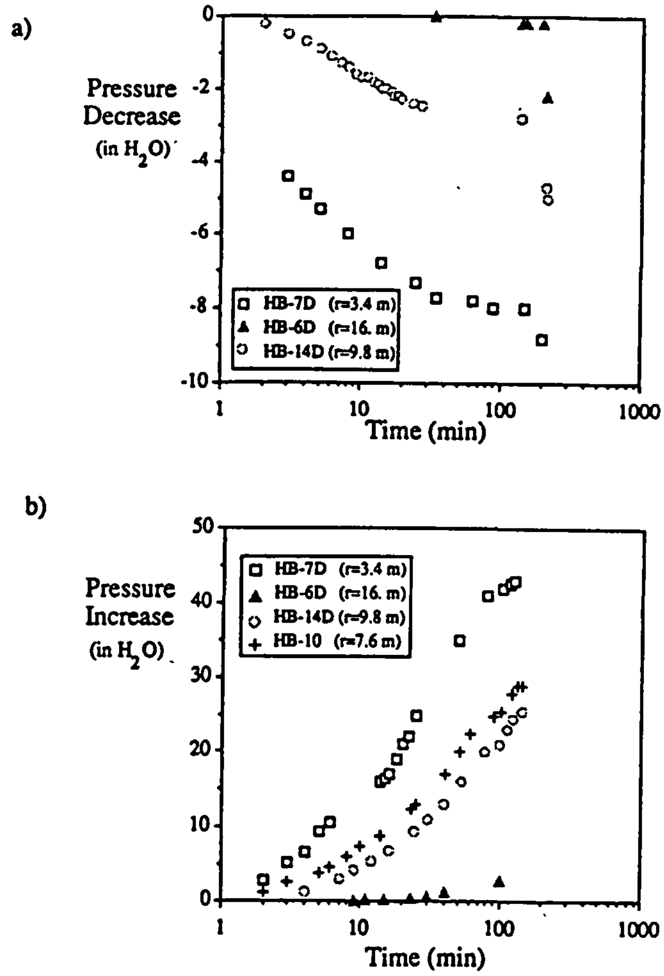


Figure 16. Air permeability test results: (a) vapor extraction test; (b) air injection test. [In H_2O] denote vacuums expressed as equivalent water column heights.

determine the permeability to vapor flow. The k values ranged from 2 to 280 darcys, with the median being ≈8 darcys.

System Design

- Number of vapor extraction wells:

Based on the 8 darcys permeability, and assuming a 15cm diameter (6 in) venting well, a 2m screened section, P_w = 0.90 atm (41 in H_2O vacuum) and R_I=12m, then Equation 5 predicts:

Q = 0.7 m^3/min = 25 cfm

Based on the preceding discussion, a minimum average flow rate of 1.5 m^3/min is needed to reduce the residual to 1000 ppm in six months. The number of wells required is then 1.5/0.7 = 2, assuming that 100 percent of the vapor flows through contaminated soils. It is not likely that this will occur, and a more conservative estimate of 50 percent vapor flowing through contaminated soils would require that twice as many wells (four) be installed.

A single vapor extraction well (HB-25) was installed in this soil layer with the knowledge that more wells were likely to be required. Its location and screened interval are shown in Figure 15. Other wells were installed in the clay layer and upper sandy zone, but in this paper only results from treatment of the lower contaminated zone will be discussed. A ground water pumping well was installed to maintain a 2m drawdown below the static water level. Its location is also shown in Figure 15.

System Monitoring

Three vadose monitoring wells similar in construction to the one pictured in Figure 14 were installed so that the soil temperature, soil-gas concentrations, and subsurface pressure distribution could be monitored at three depths. One sampling port is located in the zone adjacent to the aquifer. The vapor flow rate from HB-25 and vapor concentrations were measured frequently, and the vapor composition was determined by GC-FID analysis. In addition, the water level in the ground water monitoring wells was measured with the system pictured in Figure 13b. The results from the first four months of operation are discussed in following text

In Figure 17a the extraction well vacuum and corresponding vapor flow rate are presented. The vacuum was maintained at 0.95 atm (20 in H_2O vacuum), and the flow rate was initially 12 scfm. It gradually decreased to about 6 scfm over 80 d. For comparison, Equation 5 predicts that Q=12 cfm for k=8 darcys. Increasing the applied vacuum to 0.70 atm (120 in H_2O vacuum) had little effect on the flow rate. This could be explained by increased water table upwelling, which would act to decrease the vertical cross section available for vapor flow. The scatter in the flow rate measurements is probably due to inconsistent operation of the ground water pumping operation, which frequently failed to perform properly.

Figure 17b presents the change in vapor concentration with time. Fifteen specific compounds were identified during the GC-FID vapor analyses; in this figure the total concentration of known and unknown compounds detected between five boiling point ranges are presented:

methane - isopentane (<28 C)
isopentane - benzene (28 - 80 C)
benzene - toluene (80 - 111 C)
toluene - xylenes (111 - 144 C)
>xylenes (>144 C).

There was a shift in composition toward less volatile compounds in the first 20 days, but after that period the composition remained relatively constant. Note that there is still a significant fraction of volatile compounds present. Within the first two days the vapor concentration decreased by 50 percent, which corresponds to the time period for the removal of the first pore volume of air. Comparing the subsequent vapor concentrations with the concentrations measured in the vadose zone monitoring wells indicates that only (80 mg/L)/(240 mg/L)*100=33% of the vapors are flowing through contaminated soil.

Figure 18a presents calculated removal rates (flow rate x concentration) and cumulative amount (1 gal = 3 kg) removed during the first four months. The decrease in removal rate with time is due to a combination of decreases in flow rate and hydrocarbon vapor concentrations. After the first four months approximately one-fourth of the estimated residual has been removed from this lower zone.

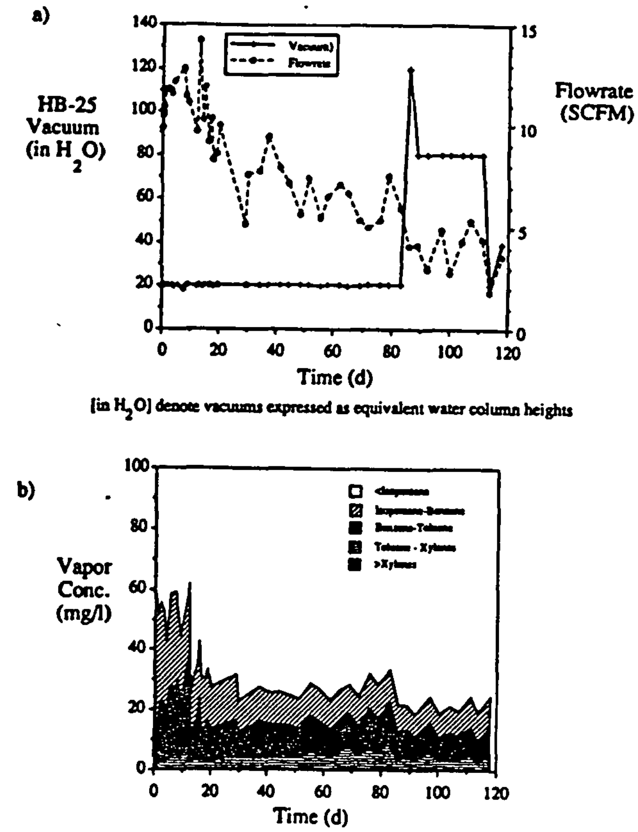


Figure 17. Soil-venting results: (a) vacuum/flow rate data, (b) concentration/composition data.

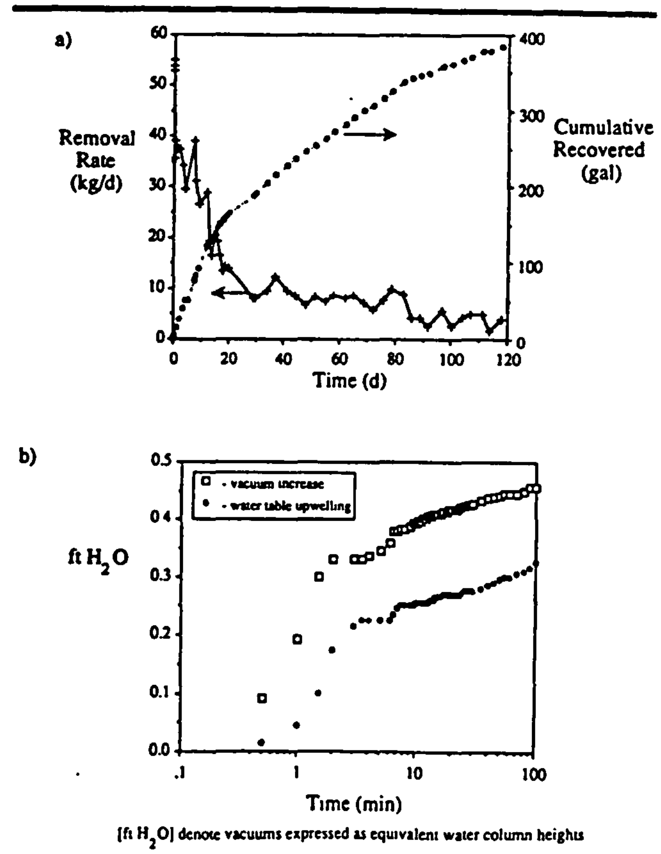


Figure 18. Soil-venting results: (a) removal rate/cumulative recovered, (b) water table rise.

On day 80 the vacuum was increased from 20 - 120 in H_2O vacuum and the subsequent increase in subsurface vacuum and water table upwelling was monitored. Figure 18b presents the results. Note that the water table rise paralleled the vacuum increase, although the water table did not rise the same amount that the vacuum did.

Figure 19 compares the reduced measured TPH vapor concentration C(t)/C(t=0) with model predictions. C(t=0) was taken to be the vapor concentration after one pore volume of air had passed through the contaminated zone (=80 mg/L), m(t=0) is equal to the estimated spill mass (=4000 kg), and V(t) is the total volume of air that has passed through the contaminated zone. This quantity is obtained by integrating the total vapor flow rate with time, then multiplying it by the fraction of vapors passing through the contaminated zone ϕ (=0.33). As discussed, the quantity ϕ was estimated by comparing soil-gas concentrations from the vadose zone monitoring installations with vapor concentrations in the extraction well vapors. There is good quantitative agreement between the measured and predicted values.

Based on the data presented in Figures 15 through 19 and the model predictions in Figure 8, it appears that more extraction wells ($\approx$ 10 more) are needed to remediate the site within a reasonable amount of time (< 2 years).

Conclusions

A structured, technically based approach has been presented for the design, construction, and operation of venting systems. While an attempt has been made to explain the process in detail for those not familiar with venting operations or the underlying governing phenomena, the most effective and efficient systems can only be designed and operated by personnel with a good understanding of the fundamental processes involved. The service station spill example presented supports the validity and usefulness of this approach.

There are still many technical issues that need to be resolved in the future. The usefulness of forced or passive vapor injection wells is often debated, as well as other means of controlling vapor flow paths (impermeable surface covers, for example). A well-documented demonstration of the effectiveness of soil venting for the removal of contaminants from low-permeability soils is also needed. It is clear from the simplistic modeling results presented in this paper that venting will be less effective in such situations. Without a comparison with other viable treatment alternatives, however, it is difficult to determine if soil venting would still be the preferred option in such cases. Other topics for future study include: enhanced aerobic biodegradation by soil venting, the possibility of decreasing residual contaminant levels in water-saturated zones by air sparging/vapor extraction, and optimal operation schemes for multiple vapor extraction well systems.

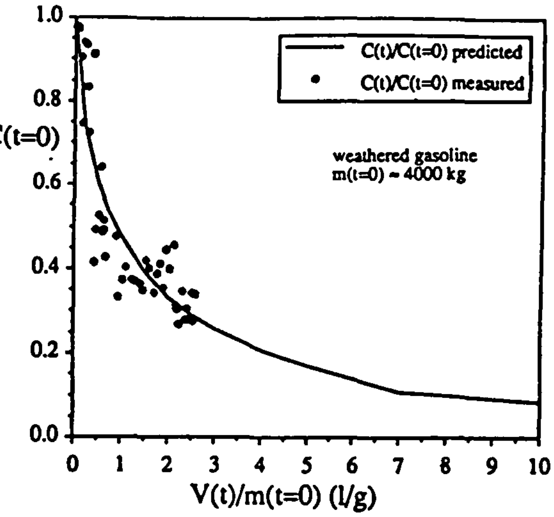


Figure 19. Comparison of model predictions and measured response.

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Biographical Sketches

Paul C. Johnson, Ph.D., joined Shell Development Co.'s (Westhollow Research Center, Room EC-649, P.O. Box 1380, Houston, TX 77251-1380) Environmental Science Department in 1987 after earning his B.S. in chemical engineering from the University of California, Davis, and his Ph.D. in chemical engineering from Princeton University. His current areas of research include the development and evaluation of soil treatment processes, modeling and measuring transport phenomena in porous media, and the development of transport models for predicting emissions and exposures used in envvironmental risk

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Curtis C. Stanley received his degree in geology with an engineering minor from North Carolina State University in 1979. He is currently a senior hydrogeologist for Shell Oil Co. (Westhollow Research Center, 2236 Two Shell Plaza, Houston, TX 77082) and is responsible for hydrogeologic response at Shell's retail facilities. Stanley is a Certified Professional Geological Scientist and also a Certified Ground Water Professional with the NWWA's Association of Ground Water Scientists and Engineers. He is also a member of API's Ground Water Technology Taskforce and is an EPA Peer Reviewer.

Marian W. Kemblowski, Ph.D., is a senior research engineer in the Environmental Science Department at Shell Development Co. (Westhollow Research Center, Houston, TX 77082) where he has worked since 1985. He obtained his M.S. degree in civil engineering from the Technical University of Warsaw, Poland, in 1973 and his Ph.D. in ground water hydrology from the Institute for Land Reclamation in Warsaw, Poland, in 1978. In 1980 - 1981 he was a visiting hydrologist in the New Mexico School of Mining and Technology. From 1981 to 1985 he worked as an assistant scientist at the University of Kansas. His principal research interests are in the areas of numerical analysis, transport in porous media, and ground water monitoring systems.

Dallas L. Byers is a technical associate in the Environmental Science Department at Shell Development. After receiving his B.S. degree in zoology from the University of Nevada, Las Vegas, he was employed by the Texas Water Quality Board as a quality control chemist for 3½ years. In 1977 he joined Shell (Westhollow Research Center, Houston, TX 77082) where he currently is providing technical assistance and support for research in the fate of chemicals in soil and gorund water.

James D. Colthart, Ph.D., has been in a variety of R&D and technical planning positions since joining Shell (Westhollow Research Center, Houston, TX 77082) in 1966. He has a B.E. from Yale University and a Ph.D. from Rice University, both in chemical engineering. Currently he is the research manager of Shell Development Co. Air, Waste, and Groundwater Group.

APPENDIX D

RIDEM GUIDANCE FOR DREDGE MATERIAL AND DISPOSAL SITE COMPATIBILITY

TRC

GENERAL INFORMATION:

DREDGE PROJECTS AND THE 401 WATER QUALITY CERTIFICATION REVIEW

Determining whether dredged materials and disposal sites are compatible has usually rested on gathering sediment samples and performing chemical analyses for each and every dredge project. An applicant, however, may be able to eliminate some of the chemical analyses by providing historic, spill and physical information regarding the dredge site and surrounding area. This information would include, but not necessarily be limited to the following: historic land use around the dredge site, former sediment analysis, date and volume of material last dredged from the project area, documentation of any previous spills, and particle size classification and percent solids from current samples.

Should the above information be insufficient for determining potential contamination, or alternatively, point directly to potentially high levels of contamination, then the applicant may be required to obtain samples for TCLP, total metals, PCB's and TBT's, and other parameters.

To initiate our review, the applicant must submit the following information:

1) A brief narrative of the site and purpose of the project, including the amount proposed to be dredged and the method of dredging.

2) A brief narrative of proposed disposal site.

3) Any historical spill or physical information regarding the dredge site and surrounding area.

4) Calculations verifying the amount of material to be dredged, the dewatering site capacity, and the disposal site capacity.

5) 8 1/2" x 11" plans drawn to scale showing the following:

   - existing and proposed contours of the dredging and disposal sites and cross-sections;
   - location of dewatering area including runoff control measures;
   - location of the disposal site and distance from the coastal feature;
   - area to be dredged; and
   - locus plan of the dredging and disposal sites.

6) A letter from the property owner indicating approval for the disposal of dredged material on their property. This letter must indicate the approved volume to be accepted.

Please note that the submission of this information often occurs before the Coastal Resources Management Council (CRMC) accepts an application or a U.S. Army Corps of Engineers request is obtained. When this happens, this office reviews the project as a "pre-application". The Department will initiate a "pre-application" review only if the applicant needs our preliminary approval to proceed with an application to ACOE or CRMC. Coordination with the CRMC and/or ACOE (as appropriate) is recommended, as a CRMC Public Notice or an ACOE request is required to formally initiate the 401 Water Quality Certification review process.

Upon receipt of the information described above, we will review the application and inform you about any further information that must be submitted or testing that must be done. If testing is required, this office will direct you as to the number of sample cores to take, where to take them, and what parameters to analyze.

Once all the information has been received, we will determine whether the project complies with our regulations and notify you about our decision. If the project is unacceptable, we will explain what our concerns are and discuss actions that can be taken to satisfy these concerns.
Please send the above requested information to my attention at the following address:

Terry J. Walsh
Department of Environmental Management
Division of Water Resources
291 Promenade Street
Providence, RI 02908-5767

Please do not hesitate to call me at 401-277-3961 if you have any questions.

BULK SEDIMENT ANALYSIS

INITIAL TEST PARAMETERS ARE THOSE LISTED IN THE LEFT HAND COLUMN OF THIS WORK SHEET. BASED UPON INITIAL TEST RESULTS SUBMITTED, THE DEPARTMENT MAY REQUIRE FURTHER PARAMETERS OR DEFINITIVE TESTS.

Area Location:______________________ Date:______________________

CRMC File No.:______________________ Reviewer's Initials:______________________

Sediment Core #							Conn. Sediment Class Levels I	II	III
Sample Depth (Ft)									
% Silt/Clay							60	60-90	90
% Solids							60	60-40	40
% Volatile Solids							5	5-10	10
Hexane Sol Fract'n (ppt)							5	5-10	10
Oil & Grease (ppm)							>400 ppm = solid waste		
[illegible]. PCB (ppm)									
Tot. TBT (ppm)									
Other									
Metals (ppm)									
Arsenic (As)							10	10-20	20
Cadmium (Cd)							5	5-10	10
Chromium (Cr)							100	100-300	300
Copper (Cu)							200	200-400	400
Lead (Pb)							100	100-200	200
Mercury (Hg)							0.5	0.5-1.5	1.5
Nickel (Ni)							50	50-100	100
Vanadium (V)							75	75-125	125
Zinc (Zn)							200	200-400	400
Suggested Classification									
Comments:									

ER COMMENTS:

TCLP TEST:

INITIAL TEST PARAMETERS ARE THOSE LISTED IN THE LEFT HAND COLUMN OF THIS WORK SHEET. BASED UPON INITIAL TEST RESULTS SUBMITTED, THE DEPARTMENT MAY REQUIRE FURTHER PARAMETERS OR DEFINITIVE TESTES.

Area Location:________________ Date:______________________

CRMC File No.:________________ Reviewer's Initials:______________

Sediment Core #							Reg. Level
Sample Depth							
Contaminant							
Arsenic							*5.0 (MG/L)*
Barium							*100.0*
Benzene							*0.5*
Cadmium							*1.0*
Carbontetrachloride							*0.5*
Chlordane							*0.03*
Chlorobenzene							*100.0*
Chloroform							*6.0*
Chromium							*5.0*
o-Cresol							*200.0*[2]
m-Cresol							*200.0*[2]
p-Cresol							*200.0*[2]
Cresol							*200.0*[2]
2,4-D							*10.0*
1,4-Dichlorobenzene							*7.5*
1,2-Dichloroethane							*0.5*

1,1-Dichloroethylene							*0.7*
2,4-Dinitrotoluene							*0.13*
Endrin							*0.02*
Heptachlor (& its OH)							*0.008*
Hexachlorobenzene							*0.13*
Hexachlorobutadiene							*0.5*
Hexachloroethane							*3.0*
Lead							*5.0*
Lindane							*0.4*
Mercury							*0.2*
Methoxychlor							*10.0*
Methylethylketone							*200.0*
Nitrobenzene							*2.0*
Pentachlorophenol							*100.0*
Pyridine							*5.0*
Selenium							*1.0*
Silver							*5.0*
Tetrachloroethylene							*0.7*
Toxaphene							*0.5*
Trichloroethylene							*0.5*
2,4,5-Trichlorophenol							*400.0*
2,4,6-Trichlorophenol							*2.0*
2,4,5-TP (Silvex)							*1.0*
Vinylchloride							*0.2*
Suggested Classification							
Comments:							

[2] *If o-,m-, and p-Cresol concentrations cannot be differentiated, the total cresol (D026) concentration is used. The regulatory level of total cresol is 200.0 mg/l*

OTHER COMMENTS:

APPENDIX E

HEALTH AND SAFETY FORMS

FIGURE 5

(CONTINUED)

Was injured using required equipment:

____

If not, how did actual equipment use differ from plan:

____

____

What can be done to prevent a recurrence of this type of accident (modification of machine; mechanical guards; correct environmental training):

____

____

Detailed narrative description (how did accident occur, why; objects, equipment, tools used; circumstance assigned duties) (be specific):

____

____

____

(Use back of sheet, as required)

Witness of accident:

____

____

Signature of Preparer ____________________

Signature of Site Leader ____________________

ACCIDENT REPORT Report No. ________

SITE: ____________________ PROJECT NO.: ________________

Location: ____

Date of Report: ______________ Preparers Name: ______________

Name and Address of Injured: ______ SSN: _____________ Age: ___

____________________________________ Sex: ___

Years of Service: ___ Time on Present Job: ___ Title/Classification: ___

Division/Department: ______ Date of Accident: ______ Time: ______

Accident Category: ___ Motor Vehicle ___ Property Damage ___ Fire

___ Chemical Exposure ___ Near Miss ___ Other

Severity of Injury or Illness: ___ Non-Disabling ___ Disabling

___ Medical Treatment ___ Fatality

Amount of Damage: $____________ Property Damaged: ____________

Estimated Number of Days Away from Job: ____________________

Nature of Injury or Illness: ______________________________

CLASSIFICATION OF INJURY:

_____ Fractures	_____ Heat Burns	_____ Cold Exposure
_____ Dislocations	_____ Chemical Burns	_____ Frostbite
_____ Sprains	_____ Radiation Burns	_____ Heat Stroke
_____ Abrasions	_____ Bruises	_____ Heat Exhaustion
_____ Lacerations	_____ Blisters	_____ Concussion
_____ Punctures	_____ Toxic Respiratory Exposure	_____ Faint/Dizziness
_____ Bites		_____ Toxic Respiratory
	_____ Toxic Ingestion	_____ Dermal Allergy

Part of Body Affected: ____________________________________

Degree of Disability: ____________________________________

Date Medical Care was Received: ____________________________

Where Medical Care was Received: ___________________________

Address (if off-site): ____________________________________

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FIGURE 5

(CONTINUED)

ACCIDENT LOCATION:

Causative agent most directly related to accident (object, substance, material, machinery, equipment, conditions):

____

____

____

Was weather a factor: ______________________________

Unsafe mechanical/physical/environmental condition at time of accident (be specific):

____

____

____

Unsafe act by injured and/or others contributing to the accident (be specific, must be answered):

____

____

____

Personal factors (improper attitude, lack of knowledge of skill, slow reaction, fatigue):

____

____

____

Level of personal protection equipment required in Site Safety Plan:

____

____

Modifications:

TRC

____